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ASTROPHYSICAL JOURNAL

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An International Review of Spectroscopy and Astronomical Physics

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ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOLUME III JANUARY 1896 NUMBER 1

ACTION OF THE EDITORIAL BOARD OF THE ASTROPHYSICAL JOURNAL WITH REGARD TO STANDARDS IN ASTROPHYSICS AND SPECTROSCOPY.

At the Congress of Astronomy and Astrophysics, held in Chicago in the summer of 1893, a committee was appointed by the Section of Astrophysics to consider and report upon the advisability of adopting certain astrophysical standards. The members of this committee, on account of the numerous duties devolving upon them during the sessions of the congresses, were unable to report upon the matter, and nothing was accomplished at that time.

The first annual meeting of the board of editors of The Astrophysical Journal, held in New York on November 2, 1894, offered another opportunity for the consideration of this subject, and much time was devoted to its discussion. Messrs. Young, Pickering, Rowland, Michelson, Hastings, Keeler and Hale were present. A full report of the meeting was sent to those members of the editorial board who were not able to attend the meeting, viz., Messrs. Cornu, Dunér, Huggins, Tacchini, Vogel, Ames, Campbell, Crew, Frost and Wadsworth, with copies of the following circular:

As a member of the Board of Editors of THE ASTROPHYSICAL JOURNAL, I am in favor of adopting the following standards in the publication of all papers in the JOURNAL:

1. The................scale of wave-lengths.

2. The.......................as the unit in which wave-lengths shall be expressed.

3. The................as the unit of measurement of motion in the line of sight.

4. That nomenclature for the lines of the hydrogen series in which the lines are designated thus:....................

5. In printing maps of spectra the......end shall be placed on the right.

6. In printing tables of wave-lengths, the........wave-length shall be placed at the top.

(Signature)..............................

I am in favor of adopting the standards named above, not only in THE ASTROPHYSICAL JOURNAL, but also in all other publications in which they might properly find a place.

(Signature)..............................

REMARKS:

Votes having been received from all of the editors, the results were presented at the second annual meeting of the board of editors, held at the Harvard College Observatory on October 17 and 18, 1895. The action of the previous year was then confirmed, and the results ordered published.

The *Rowland Scale of Wave-lengths*, as represented by the wave-length tables now being published in THE ASTROPHYSICAL JOURNAL, was adopted by a unanimous vote.

All of the editors, with the exception of Professor Vogel, voted that the *ten millionth of a millimeter*, Ångström's unit, known also as the "tenth-meter," be adopted as the unit in which wave-lengths shall be expressed. Professor Vogel preferred to use the *millionth of a millimeter*, and several others also favored this unit, though they voted with the majority. Professor Cornu's statement of his own position on the question no doubt expresses a not uncommon feeling: "J'accepte le *dix-millionième de millimétre* comme unité pour l'expression des longueurs d'onde, mais c'est *uniquement* parceque la grande majorité des physiciens et astronomès l'emploient dans leurs publications. Je regrette vivement que l'on ait abandonné l'idée si simple des promoteurs du système mètrique, qui consistait à procéder dans le choix des multiples ou sous-multiples par des *puissances de 1000.* Les préfixes *micro* et *méga*, designant $\frac{1}{1000000}$ et 1000000 ou $10^{\pm 6}$, proposés par les promoteurs du système C. G. S., étaient excellents. Mais eux-mêmes ont abandonné cette voie : après avoir choisi l'*Ohm* 10^9 unité C. G. S. de resistance ils ont maladroitement adopté le *Volt* 10^8 unité C. G. S. de potential, détruisant ainsi de leurs propres mains la symetrie de la loi de Ohm et se condamnant à accepter l'*Ampère* 10^{-1} C. G. S. comme unité de courant. . . . . "

The *kilometer* was unanimously adopted as the unit to be used in measurements of motion in the line of sight.

The nomenclature proposed by Vogel and Huggins for the hydrogen series, in which the lines are designated $H\alpha$, $H\beta$, $H\gamma$, etc., beginning at the red end and continuing through the entire series, was unanimously adopted.

With the exception of Professors Vogel and Campbell, all of the editors favored printing maps of spectra with the red end on the right, and tables of wave-lengths with the shorter wave-lengths at the top. Professor Vogel preferred the opposite arrangement in each case. Professor Campbell stated that he had no preference, but agreed to follow the decision of the Board.

All of the editors favored the use of the standards for which they had voted, not only in THE ASTROPHYSICAL JOURNAL, but also in all other publications of a similar character.

It is greatly to be hoped that the action of the majority, which has been accepted in THE ASTROPHYSICAL JOURNAL from the outset, will be concurred in by all astronomers, astrophysicists and physicists, and adopted in their publications.

ON THE SPECTRUM OF CLÈVEITE GAS.[1]

By C. Runge and F. Paschen.

The results of this investigation have already been published in papers communicated to the Berlin Academy of Sciences and the British Association. The determinations of the wave-lengths there presented were, however, only preliminary, and many important details were omitted. The final values resulting from a complete examination of our plates are now given, together with a full report on our experiments and on the conclusions arrived at. The gas was obtained by boiling pulverized clèveite from Moss in dilute sulphuric acid. Before introducing the powder into the flask care was taken to expel all air by the vapor of the boiling sulphuric acid. The gas, which was evolved slowly, was collected over a solution of caustic potash and mixed with an abundance of oxygen. It was sparked for several days until the volume, which at first decreased considerably, was not further diminished by a whole days sparking. The sparks showed the spectrum of clèveite gas from the beginning. The oxygen was absorbed by admitting a solution of pyrogallol to the solution of caustic potash and the remaining gas was brought into a vessel, previously exhausted, containing phosphoric acid. The vessel was provided with a small chamber that could be closed by stopcocks and served to separate from the supply of gas a small quantity with which to fill the vacuum tubes. The tubes were made as shown in Fig. 1. *b* is a window of glass, quartz or fluor-spar, according to the purpose, fastened with sealing wax. *C,C* are two cylinders of aluminum foil, each pressing against two platinum wires (*p,p*). This arrangement of the electrodes is a plan devised by Rowland.[2] It allows stronger currents to pass

---

[1] *Sitz. d. K. Akad. d. W. Berlin*, July, 1895, pages 639 and 759. A translation of this paper is published in *Phil. Mag.* September, 1895. See also a paper read before the British Association at Ipswich. *Nat.* 52, 520, Sept. 26, 1895.

[2] Ames, *Phil. Mag.* 30, 1890.

through the tube without bursting the glass[1] and therefore gives greater brightness than the ordinary plan. At the same time the tube may be used end-on.

The tube is first completely exhausted and dried at the pump. After that a strong induction current is passed through it, the direction of the current being frequently reversed. At the same time the tube is heated with a Bunsen burner, especially in the capillary part and in the region of the electrodes, to as high a temperature as it will bear, and the gas which is evolved is removed by the pump from time to time. This is continued until the tube will not transmit even a strong induction current and the last phosphorescent glow ceases. It is then filled with the gas, and an induction current, the direction of which is frequently reversed, is again allowed to pass. Hydrogen is evolved again as a rule. The tube is then again heated, sparked and exhausted, and this treatment is continued until hydrogen, the most persistent impurity, no longer shows its lines in spite of strong heating and powerful induction currents. About half of the tubes filled in this manner and sealed off when in this condition, remain good for a long time and show the hydrogen lines and other impurities only dimly if at all. A tube may be considered good, if it shows the line 7282 as clearly as or better than the red hydrogen line 6563.

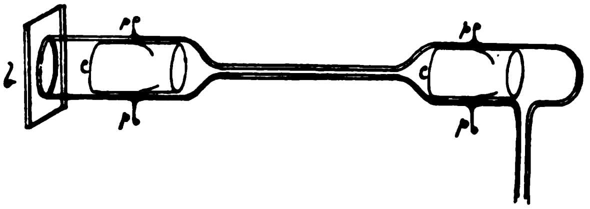

FIG. 1.

Almost all the stronger lines were interpolated directly from Rowland's standard wave-lengths of iron and sodium lines. The iron lines were obtained by placing two iron electrodes close before the slit. The vacuum tube was arranged end-on, and an image of the narrow part was thrown on to the slit so that the rays passed through the iron spark. For accurate determinations we found it necessary to screen off the light from all those parts of the slit that were not fully illuminated by both light sources. The spectrum of a Rowland concave grating[1] being astigmatic, the middle of a line may be slightly shifted by superposed astigmatic images of other parts of the slit. But if both light sources illuminate the same parts of the slit the lines of both sources will be affected equally, and the wave-lengths of one source may be safely referred to those of the other. The sodium lines used as standards were the D lines and the next pair of the principal series at 3303. These lines are emitted from the vacuum tube as soon as the glass gets sufficiently heated. They are very suitable as standards, being extremely narrow and symmetrical. One cannot say the same of all the iron spark lines, and we think that we should have been able to increase the accuracy of our determinations in some degree if we could have used finer standards. The exposures have necessarily varied widely. Very bright lines like 3889 can be photographed in a few seconds, while to bring out the end of a series we have in some cases exposed all night long. A good induction coil with a reliable break was indispensable for this purpose, and we are greatly indebted to Mr. Ernest Porter, who was kind enough to place at our disposal an induction coil made by himself, which works admirably. We did not take pains to place the camera in the normal of the grating. Thus the scale on the plates does not vary quite so slowly as it would have done had we employed Rowland's method of mounting the grating. But the scale was sufficiently constant for the short strip of the spectrum covered by a single series of measures. The lines were always interpolated linearly from a number of standard wave-lengths by the method of least squares. At the same time this method gives us the mean error of a single determination, assuming the standard values to be absolutely correct, and, on the supposition that the measured clèveite line is as fine as the standard lines, its mean error is the same. If it is measured on several plates the weight of each determination is taken inversely proportional to the square of the mean error. The weight of the mean is equal to the sum of the weights of the single determinations, and as the mean error is inversely proportional to the square root of the weight, we can calculate the mean error of the mean from the mean error of the single determinations. This is one way of calculating the mean error of the mean; another method is to calculate it from the differences between the single determinations and their mean. The first value would not be influenced by a constant error in one of the plates, but the second value would. If the two agree one may therefore conclude that there is either no constant error or the same constant error in all the plates. If they do not agree it becomes probable that either there is a constant error in some of the plates or the clèveite line has not been measured with the same accuracy as the standard lines. The two values are given in the table, and the accuracy of the determinations is indicated by the fact that they agree well on the whole. The plates were measured on an "Abbe Comparator" manufactured by Zeiss of Jena. The errors due to this instrument are certainly only a fraction of the error due to the lines not being more accurately defined. With a fine object the error of the instrument is less than $0^{\mathrm{mm}}.001$, which in the first order of our Rowland grating corresponds to about 0.002 tenth-meters.

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[1] The current was taken from a storage battery of six cells. The strength of the primary current was from one to three ampères.

---

[1] The one we used has a ruled surface of 6 inches, 20,000 lines to the inch and a radius of curvature of 6.5 meters.

Special care has been taken to determine the distance between the components of the double lines. They were photographed in the second and third orders, and the distance was measured as accurately as possible. The double line 7065 was not photographed but measured by eye observations with a micrometer. The following table contains all the double lines. The first column gives the wave-lengths as they were determined by interpolation from Rowland's standards or indirectly from lines determined from Rowland's standards. The second column contains the difference of these wave-lengths, the third the mean

TABLE OF WAVE-LENGTHS.

Wave-length	Intensity [1]	Mean Error		Number of Plates	Number of Determinations	Remarks
		I	II			
2663.3	< 1	....	....	2	2	*
2677.2	< 1	....	....	3	3	
2696.230	< 1	0.013	....	1	1	†
2723.275	1	0.010	0.002	3	3	
2763.900	2	0.008	0.013	3	4	
2829.173	4	0.006	0.006	3	4	
2945.220	6	0.003	0.004	7	8	† and from the sodium lines D_1, D_2. In second order the line is close to D_2.
3176.6	< 1	....	....	1	1	* Very faint, doubtful.
3187.830	8	0.006	0.010	4	4	†
3196.81	< 1	....	....	1	1	* Faint.
3211.626	< 1	....	0.011	1	2	*
3231.327	< 1	....	0.004	3	4	Determined from sodium lines in Rowland's standards, from neighboring clèveite lines and indirectly.
3258.336	< 1	....	0.005	3	3	
3296.900	< 1	....	0.008	3	3	Determined from iron and sodium lines in Rowland's standards and also from neighboring clèveite lines.
3354.667	1	0.004	0.005	5	5	Determined from iron and sodium lines in Rowland's standards.
3447.734	2	0.004	0.004	4	5	†
3456.9	< 1	....	....	1	..	Doubtful *
3461.4	< 1	....	....	1	..	Doubtful
3466.04	< 1	0.020	0.004	1	2	
3471.93	< 1	0.016	0.02	1	3	
3479.10	< 1	0.016	0.01	1	3	
3481.6	....	....	....	1	1	Doubtful
3487.87	< 1	0.016	0.004	1	3	
3490.77	< 1	0.02	0.01	1	2	
3498.78	< 1	0.014	0.02	4	5	
3502.47	< 1	0.02	0.02	1	3	
3512.65	< 1	0.013	0.016	5	6	
3517.48	< 1	0.014	0.02	2	4	
3530.646	< 1	0.015	0.008	6	8	
3536.963	< 1	0.006	0.019	3	3	
3554.594	1	0.014	0.001	2	2	†
3554.725	< 1	....	....	1	1	Faint companion of 3554.594, from which its position was determined.
3563.125	< 1	0.008	0.006	3	4	*
3587.426	2	0.004	0.004	5	5	†
3587.570	< 1	0.004	0.006	5	5	
3599.472	< 1	0.004	0.007	3	3	

---

* Determined from neighboring clèveite lines.

† Determined from iron lines in Rowland's table of standard wave-lengths.

[1] Much weight must not be given to the numbers 15, 10, 9, ... , 2, 1 and < 1 estimating the intensity. The energy of the light might just as well be supposed proportional to the squares or the third powers or any other function of the given numbers.

TABLE OF WAVE-LENGTHS.—*Continued.*

Wave-length	Intensity	Mean Error		Number of Plates	Number of Determinations	Remarks
		I	II			
3599.610	< 1	....	....	1	1	Faint companion of 3599.472, from which its position was determined.
3613.785	3	0.004	0.002	2	2	†
3634.393	2	0.003	0.002	4	5	
3634.523	< 1	0.003	0.004	4	5	
3652.121	1	0.003	0.006	3	3	
3652.269	< 1	0.003	0.005	2	2	
3705.151	3	0.002	0.001	5	7	
3705.287	< 1	0.002	0.002	5	7	
3733.004	1	0.002	0.007	3	3	
3733.142	< 1	0.002	0.004	3	3	
3756.24	< 1	....	....	1	1	Determined as in the case of the line 3787.64. Lines weak and diffuse.
3768.95	< 1	....	....	1	2	
3770.72	< 1	....	....	1	2	Determined as in the case of the line 3787.64. The line is weak and diffuse, and could be seen on but one plate, and only with low power. An error of 0.2 is not impossible.
3785.031	< 1	0.007	0.001	2	2	Determined as in case of the line 3805.9.
3787.64	< 1	....	....	1	2	Determined from the neighboring clèveite lines; visible on but one plate, and only with low power. The accuracy is, therefore, much smaller than that of the other determinations.
3805.900	< 1	0.007	0.005	2	2	Determined from lines of the cyanogen band given in Rowland's table of solar spectrum wave-lengths, and from lines measured on other plates based on standards.
3819.751	4	0.002	0.001	3	4	†
3819.899	< 1	0.002	0.004	3	4	†
3833.710	< 1	0.009	0.011	3	3	Determined by lines of the cyanogen band given in Rowland's solar spectrum wave-lengths, and indirectly.
3838.240	< 1	0.010	0.014	2	2	
3867.613	2	0.002	0.002	5	5	†
3867.766	< 1	0.004	....	1	1	†
3871.954	< 1	0.009	0.010	3	3	Determined by lines from Rowland's solar spectrum wave-lengths and indirectly.
3878.330	< 1	0.009	0.004	3	3	
3888.785	10	0.002	0.004	7	7	Determined from Rowland's standards and also indirectly. Difficult line on account of its enormous energy. Ghosts of the eighth order generally visible on both sides. The ghosts were used in the determination.
3926.678	1	0.005	0.005	4	5	Determined from Rowland's standards, and on one plate indirectly from lines based on Rowland's standards.
3936.064	< 1	0.008	0.011	2	2	Determined indirectly from lines based on Rowland's standards.

TABLE OF WAVE-LENGTHS.—*Continued.*

Wave-length	Intensity	Mean Error		Number of Plates	Number of Determinations	Remarks
		I	II			
3964.875	4	0.004	0.003	4	4	†
4009.417	1	0.003	0.002	3	3	†
4024.136	< 1	0.004	0.006	2	2	†
4026.342	5	0.003	0.005	3	3	†
4026.512	< 1	0.003	0.008	3	3	†
4120.973	3	0.006	0.003	3	4	† and partly from Rowland's table of solar spectrum wave-lengths.
4121.143	< 1	0.006	0.003	3	4	
4143.919	2	0.006	0.003	3	4	
4169.131	1	0.007	0.006	2	2	
4388.100	3	0.004	0.004	4	4	†
4437.718	1	0.004	0.005	4	4	†
4471.646	6	0.004	0.005	4	4	†
4471.858	< 1	0.004	0.006	4	4	
4713.252	3	0.011	0.014	4	4	Determined from second order iron lines from Rowland's table of standards.
4713.475	< 1	0.016	0.004	2	2	
4922.096	4	0.013	0.010	5	5	Determined from second order iron lines measured by Kayser and Runge, and corrected to agree with Rowland's standards.
5015.732	6	0.006	0.007	4	4	Determined from second order iron lines in Rowland's table of standards.
5047.816	2	0.007	0.007	3	3	
5875.870	10	0.006	0.005	6	9	Determined from second order iron lines and from the D lines, all Rowland's standards.
5876.209	1	0.007	0.004	6	6	
6678.37[1]	6	0.005	0.004	2	2	Determined from the two Rowland standards Na 3302 and 3303 in the second order, and some lines of a nitrogen band previously determined by iron lines from Rowland's table of standards.
7065.48[1]	5	0.025	0.030	1	2	Determined from the helium lines 3587, 3554, 3530 in the second order.
7066.00[1]	< 1	....	0.031	..	..	Determined from 7065.48 by measuring the distance visually with a micrometer in the first order of our large concave grating.
7281.81	3	....	0.05	..	..	Measured visually with a spectrometer in the second, third, and fourth orders of a plane Rowland grating.
11170	15	....	48.	..	..	Bolometric measurements. See note at the end of this paper.
20400	10	....	80.	..	..	

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[1] These lines, 6678.37, 7065.48 and 7066.00, are close to two red argon lines, but they are by no means coincident with them. The wave-lengths of the argon lines are 6677.39 (m. e. 0.08), 7067.55 (m. e. 0.06). Ramsay's suggestion of a constituent common to argon and helium, which was based on the apparent coincidence of these lines, thus lacks confirmation.

error of this difference, the fourth the difference of the wave-lengths measured in higher orders, the fifth the mean error, the sixth the mean of the two differences. The seventh column gives the corresponding differences of wave-numbers in units of the eighth figure. The eighth column will be explained later.

Wave-length	Difference	Mean error	Difference measured in higher orders	Mean error	Mean	Corresponding difference of wave-numbers	
3554.594 3554.725	...	..	131	..	131	1131	.127
3587.426 3587.570	144	7	143	..	143	1111	.130
3599.472 3599.610	...	..	138	.. [1]	138	1066	.130
3634.393 3634.523	130	5	144	8	134	1014	.133
3652.121 3652.269	148	8	133	5	143	1072	.134
3705.151 3705.287	136	3	135	5	136	991	.138
3733.004 3733.142	138	8	...	..	138	991	.140
3819.751 3819.899	148	4	148	2	148	1014	.147
3867.613 3867.766	153	4	150	2	151	1009	.151
4026.342 4026.512	170	9	163	1	163	1006	.163
4120.973 4121.143	170	8	170	2	170	1001	.171
4471.646 4471.858	212	8	200	2	201	1005	.203
4713.252 4713.475	223	21	223	2	223	1004	.224
5875.870 5876.209	339	9	343	3	343	993	.348
7065.49 7066.00	...	..	516	6	516	1034	.503
					Mean :	1007	(mean error 3.6)

It appears that the difference of wave-numbers is the same for all the double lines. The mean is 1007, the deviation from the mean surpassing the mean error only in three cases out of 12. That the difference of wave-numbers is constant we are the more ready to believe from the same fact having been observed in the spectra of many other elements, including Na, K, Rb, Cs, Cu,

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[1] The first three differences are doubtful, the lines being difficult to separate.

Ag, Al, In, Tl. If it is constant, then the wave-length differences ought to be those given in the eighth column, and we may be justified in correcting the wave-lengths of the two components of each double line so that the difference becomes equal to the calculated number. Taking account of the different accuracy with which the components have been measured, the following wave-lengths would be arrived at:

WAVE-LENGTHS CORRECTED TO CONSTANT DIFFERENCE OF WAVE-NUMBERS.

....	3819.751
....	3819.898
3554.594	3867.613
3554.721	3867.764
3587.430	4026.344
3587.560	4026.507
3599.472	4120.973
3599.602	4121.144
3634.392	4471.650
3634.525	4471.853
3652.129	4713.252
3652.263	4713.476
3705.150	5875.866[1]
3705.288	5876.214
3733.002	7065.48
3733.142	7065.98

In our former publications we have also given 2764, 2829, 2945, 3188, 3613, 3888, 3965 as double. This appears to have been an error. We have convinced ourselves since that they are single so far as we are able to judge in the second and third order of a grating of 110000 lines, except perhaps the line 3889. In the third order there appears to be a fainter component, the wave-length of which is 0.05 larger.

The distribution of the lines in the spectrum of clèveite gas

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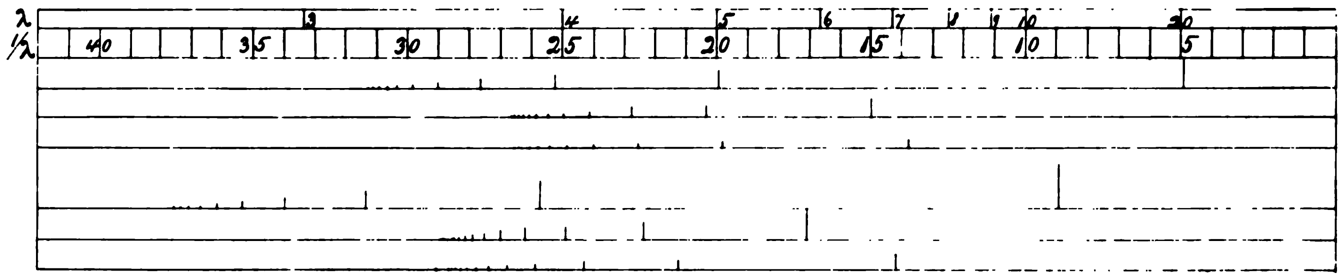
[1] This difference between the components of D_3 agrees better than our first determinations with the measurements of Hale in the spectrum of the Sun's limb. Hale finds 0.357, which differs from the value given above by only 0.009. It may be of interest to note that the stronger component of D_3 is clearly seen to be reversed on the photographs as well as by eye observation. But the reversal is so fine that it only shows in the second order.

PLATE III.



shows a beautiful regularity when the lines are separated into six series. In the accompanying figure (Plate III) the lines are drawn to the scale of wave-numbers, the intensity being signified by the length of the lines.

The regularity would be destroyed if the six groups were drawn promiscuously all in one row. We do not think that any one can believe this regular distribution to be accidental, but we can give still better proof of a law connecting the members of each series. The wave-lengths of each series may be calculated from a formula:

$$\frac{1}{\lambda} = A + \frac{B}{n^2} + \frac{C}{n^3}$$

where A, B, C are constants and where n represents the series of whole numbers beginning with 2 or with 3. The last two series consist of double lines. At least all the stronger lines of the two series have been seen to be double. The lines corresponding to shorter wave-lengths become too weak and too diffuse for the duplicity to be recognized, though they are very likely double. There should be two formulæ for each of the last two rows of the drawing, one for the stronger and one for the weaker component. We give only the formula for the stronger component; the other may easily be deduced by subtracting 100.7 from the constant A. For as we have shown above, the difference of wave-numbers of the two components is constant. To calculate the formulæ all the wave-lengths have been reduced to a vacuum according to the determinations of Kayser and Runge,[1] and $\frac{1}{\lambda}$ is calculated to such a number of figures that the number given represents the number of waves that make up one meter *in vacuo*. The differences between the observed and the calculated values might be made still smaller by calculating the constants of the formula not only to suit three consecutive observed values but so as to make all of the deviations as small as possible. But we thought it more instructive to show how accurately all of the wave-numbers may be calculated from three of them.

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[1] KAYSER und RUNGE, "Die Dispersion der Luft." *Abh. d. K. Akad. d. W. Berlin*, 1893.

PRINCIPAL SERIES.

$$\text{Wave-number} = 3202986 - 1.09537 \times \frac{10^7}{n^2} + 1.9636 \times \frac{10^5}{n^4}$$

n	Wave-length in air at 20° C. and 760^{mm}	Wave-number observed	Wave-number calculated	Difference	Corresponding difference in tenth-meters	Remarks
14	3176.6 ?	3147127	3147171	−44	+0.04	Doubtful
13	........[1]	....	3138261	....	.....	
12	3196.81	3127232	3127032	200	−0.20	
11	3211.626	3112806	3112607	199	−0.21	
10	3231.327	3093828	3093645	183	−0.19	
9	3258.336	3068183	3068024	159	−0.17	
8	3296.900	3032296	3032218	78	−0.08	
7	3354.667	2980082	2980014	68	−0.08	
6	3447.734	2899641	2899626	15	−0.02	
5	3613.785	2766409	These three values determine the constants	0	0.00	
4	3964.875	2521448		0	0.00	
3	5015.732	1993181		0	0.00	
2	20400.	4901...	489106	10..	—42.	The mean error is 80.

[1] This line has not been seen. As the last lines of the series are very faint, they could be brought out only by long exposure. But this broadened the strong line 3188 to such an extent that weak lines in the neighborhood cannot advantageously be searched for.

FIRST SUBORDINATE SERIES.

$$\text{Wave-number} = 2717516 - 1.097587 \times \frac{10^7}{n^2} - 2.726 \times \frac{10^4}{n^4}$$

n	Wave-length in air at 20 C. and 760^{mm}	Wave-number observed	Wave-number calculated	Difference	Corresponding difference in tenth-meters	Remarks
14	3756.24	2661495	2661507	—12	+0.017	
13	3768.95	2652520	2652558	−38	+0.054	
12	3785.031	2641250	2641279	—29	+0.042	
11	3805.900	2626768	2626786	−18	+ 0.026	
10	3833.710	2607713	2607730	−17	+0.025	
9	3871.954	2581957	2581974	−17	+0.026	
8	3926.678	2545975	2545965	+10	—0.015	
7	4009.417	2493437	2493439	− 2	+0.003	
6	4143.919	2412507	2412504	+ 3	—0.005	
5	4388.100	2278263	These three values determine the constants	0	0.000	
4	4922.096	2031098		0	0.000	
3	6678.37	1496965		0	0.000	

SECOND SUBORDINATE SERIES.

$$\text{Wave-number} = 2716859.5 - 1.088256 \times \frac{10^7}{n^2} - 3.596 \times \frac{10^6}{n^3}$$

n	Wave-length in air at 20° C. and 760 mm	Wave-number observed	Wave-number calculated	Difference	Corresponding difference in tenth-meters	Remarks
13	3770.72	2651274	2650829	+ 445	— 0.63	
12	3787.64	2639431	2639205	+ 226	— 0.33	
11	......[1]	....	2624219	.....	......	
10	3838.240	2604636	2604438	+ 198	— 0.29	
9	3878.330	2577712	2577574	+ 138	— 0.21	
8	3936.064	2539904	2539796	+ 108	— 0.17	
7	4024.136	2484316	2484282	+ 34	— 0.06	
6	4169.131	2397918	These three values determine the constants	0	0.00	
5	4437.718	2252789		0	0.00	
4	5047.816	1980512		0	0.00	
3	7281.81	1372913	1374501	— 1588	+ 8.4	

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[1] There is a line at 3809.22, wave-number 2624478, but we believe it to be an impurity, which covers the line of the series. It looks too sharp and somewhat too strong to belong to the series.

PRINCIPAL SERIES.

$$\text{Wave-number} = 3845532.4 - 1.098919 \times \frac{10^7}{n^2} - 1.4507 \times \frac{10^6}{n^3}$$

n	Wave-length in air at 20° C. and 760mm	Wave-number observed	Wave-number calculated	Difference	Corresponding difference in tenth-meters	Remarks
11	2663.3	3753645	3753623	+ 22	— 0.016	
10	2677.2	3734158	3734190	— 32	+ 0.023	
9	2696.230	3707804	3707873	— 69	+ 0.050	
8	2723.275	3670983	3670993	— 10	+ 0.007	
7	2763.900	3617028	3617034	— 6	+ 0.005	
6	2829.173	3533582	3533561	+ 21	— 0.017	
5	2945.220	3394359	These three values determine the constants	0	0.000	
4	3187.830	3136041		0	0.000	
3	3888.785	2570782		0	0.000	The mean error is 48.
2	11170...	8951...	916897	— 218..	+ 270	

FIRST SUBORDINATE SERIES.

$$\text{Wave-number} = 2922435 - 1.098363 \times \frac{10^7}{n^2} - 1.67 \times \frac{10^4}{n^3} \; *$$

n	Wave-length in air at 20° C. and 760 mm	Wave-number observed	Wave-number calculated	Difference	Corresponding difference in tenth-meters	Remarks
19	3456.9 ?	2891943	2892007	— 64	0.08	Doubtful.
18	3461.4 ?	2888193	2888532	— 339	0.41	Doubtful.
17	3466.04	2884327	2884426	— 99	0.12	
16	3471.93	2879433	2879526	— 93	0.11	
15	3479.10	2873500	2873614	— 114	0.14	
14	3487.87	2866274	2866390	— 116	0.14	
13	3498.78	2857337	2857436	— 99	0.12	
12	3512.65	2846056	2846150	— 94	0.12	
11	3530.646	2831549	2831649	— 100	0.13	
10	3554.594	2812473	2812582	— 109	0.14	
9	3587.426	2786734	2786812	— 78	0.10	
8	3634.393	2750723	2750783	— 60	0.08	
7	3705.151	2698192	2698231	— 39	0.05	
6	3819.751	2617244	2617257	— 13	0.02	
5	4026.342	2482956	These three values determine the constants	0	0.00	
4	4471.646	2235697		0	0.00	
3	5875.870	1701413		0	0.00	

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* It is curious that while in the other five series the first line always corresponds to the smallest positive value of *n* for which the formula gives a positive value, in this case it does not. Giving *n* the value 2 we get λ = 57326. But there is no line there of an intensity corresponding to that of the first member of this series. We particularly searched for it, and are sure that between λ = 20400 and λ = 100000 there is no line the energy of which surpasses the heat of the glass tube in this part of the spectrum. See the note at the end.

SECOND SUBORDINATE SERIES.

$$\text{Wave-number} = 2919796.7 - 1.061524 \times \frac{10^7}{n^2} - 8.656 \times \frac{10^6}{n^3}$$

n	Wave-length in air at 20° C. and 760 mm	Wave-number observed	Wave-number calculated	Difference	Corresponding difference in tenth-meters	Remarks
15	3481.6	2871437	2870052	+ 1385	— 1.69	
14	3490.77	2863893	2862483	+ 1410	— 1.72	
13	3502.47	2854327	2853045	+ 1282	— 1.57	
12	3517.48	2842147	2841071	+ 1076	— 1.33	
11	3536.963	2826492	2825564	+ 928	— 1.16	
10	3563.125	2805739	2804988	+ 751	— 0.95	
9	3599.472	2777408	2776871	+ 537	— 0.70	
8	3652.121	2737371	2737027	+ 344	— 0.46	
7	3733.004	2678061	2677923	+ 138	— 0.19	
6	3867.613	2584855	These three values determine the constants	0	0.00	
5	4120.973	2425939		0	0.00	
4	4713.252	2121094		0	0.00	
3	7065.48	1414948	1419733	— 4785	+24.	

The deviations of the calculated values from the observed wave-numbers in most cases exceed the limits of error, but nevertheless we think it is clearly shown that there is a numerical relation connecting all the lines of a series, though the exact law has not yet been found. Series of lines similar to these have been observed in the spectra of many other elements,[1] and formulæ similar to those given above have been calculated. Kayser and Runge have preferred the form

$$\frac{1}{\lambda} = A + \frac{B}{n^2} + \frac{C}{n^4},$$

while the formulæ given above have a term $\frac{C}{n^3}$ instead of $\frac{C}{n^4}$. We have found the agreement decidedly closer with $\frac{C}{n^3}$ and therefore prefer this form, though the difference is not great. Both forms are only approximations to the real law, which is probably represented by an infinite series of negative powers of n.

The second constant B is nearly the same in all six formulæ. Indeed it is nearly the same in all formulæ for all series of lines that have been observed in the spectra of any of the elements. For the hydrogen series, for instance, this constant is 1.096732×10^7. It must have some important physical meaning relating to a quality common to all elements in this state of vibration. It may further be seen from the drawing as well as from the formulæ that the third series approaches the same limit as the second, and that the sixth series approaches the same limit as the fifth. For the constant A is very nearly the same for each pair. We believe that for the exact law the limit towards which the wave-numbers approach should be exactly the same. For the discrepancy which still exists between the two values of A becomes much smaller if the constants are calculated from three wave-numbers nearer the end of the series. Thus, calculating the formula of the sixth series from the wave-numbers corresponding to $n = 9, 10, 11$ we find for A the value 2921886, while it is 2922435 for the fifth series, so that the calculated limit of the sixth series would be only 0.65 tenth-meters to the less refrangible side of the calculated limit of the fifth series.

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[1] RYDBERG, "Recherches sur la constitution des spectres d'émission des éléments chimiques." *Svenska vetensk. Akad. Handl.* **23**, No. 11. KAYSER und RUNGE. *Abh. d. K. Akad. d. W. Berlin*, 1888–93.

This phenomenon of two series of lines approaching the same limit is common to the spectra of all elements in which series of lines have been observed except hydrogen. In all these spectra we find two series of single, double or triple lines apparently approaching the same limit.[1] All the double or triple lines forming two such series have the same difference of wave-numbers. But there is no case in all the eighteen spectra, where series of lines have been observed, of more than two series approaching the same limit. Therefore, we come to the conclusion that clèveite gas consists of two elements, one corresponding to the second and third series (single lines), and the other corresponding to the fifth and sixth series (double lines with constant difference of wave-numbers). If this is true the name *Helium* should be given only to the second element, the spectrum of which includes D_3. The first element Professor Stoney has proposed to call *Parhelium.*[2] In all the spectra of the alkalis there is a third series, in addition to the two that approach the same limit. This third series is very strong; it embraces several lines of the other series between each of its members, and finally runs out on the more refrangible side of the spectrum. It has been called the principal series by Rydberg, and by Kayser and Runge, while the other two have been called subordinate series. Of the two subordinate series one is invariably the stronger. It is called the first subordinate series and the other the second subordinate series. These designations have been extended to the other spectra, where two series of lines approaching the same limit have been observed, and we shall also apply them to the spectra of helium and parhelium. The two remaining series we take to be the two principal series corresponding, the one to helium and the other to parhelium, as they show the same characteristics as the principal series in the spectra of the alkalis. As the two subordinate series of helium are stronger than those of parhelium, we take the stronger of the two (the fourth in the drawing), to be the principal series of helium. The first three rows in the drawing represent the spectrum of parhelium, and the other three that of helium. Both spectra now closely resemble any of the spectra of the alkalis. We also note that, as in the spectra of the alkalis, the first subordinate series has a smaller spread than the second, corresponding intervals being smaller for the first; or, as we might also express it, the formula of the first subordinate series has a smaller value of C. The lines are now all disposed of in the two systems, which we think justifies the conclusion that the gas does not contain more than these two constituents.

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[1] In the spectrum of rubidium and cæsium only one member of the "second subordinate series" seems to have been found. The place where it ends therefore cannot be deduced.

[2] We shall for convenience use this name in the following. We are well aware that, although strong reason for supposing the gas to consist of two constituents has been given by our work, conclusive proof is still wanting.

From the analogous fact in the spectra of the alkalis, we should expect the first line of the principal series of helium to be a double line, with the same difference of wave-numbers as the double lines in the subordinate series. The following lines of the principal series should also be double lines, but the differences of wave-numbers should decrease rapidly, *e. g.*, from the first to the second line in the proportion of about three to one. It is impossible to test this conclusion as to the first line, for the bolometer is not sufficiently sensitive to bear a dispersion that would separate the components. But, as to the second line, the possibility of the test is just within reach. The difference of wave-numbers should be about one-third of 100.7, which for the line 3889 comes to 0.051 tenth-meters. Indeed, on two of our photographs of the line in the third order a faint component is to be seen on the less refrangible side, the distance of which we measured as 0.057 on one plate, and 0.051 on the other. But we feel not quite sure of the result, because on some of the plates spurious lines have made their appearance, due probably to defects in the apparatus.

In the spectra of the alkalis, the distance between the components of the double lines increases with the atomic weight, in such a manner that the difference of wave-numbers is roughly proportional to the square of the atomic weight.

	Difference of wave-numbers	Atomic weight	Difference divided by square of atomic weight
Na	1710	23	3.1
K	5680	39	3.7
Rb	23440	85	3.2
Cs	54500	133	3.1

If helium followed the same law, the atomic weight could be calculated from the difference of wave-numbers of the double lines, which we found to be 100.7. If the atomic weight is x, we should have 100.7 between about $3.1 \times x^2$ and $3.7 \times x^2$, that is, x between about 5.7 and 5.2. As clèveite gas has been found to be monatomic, with a density of about 2 (hydrogen 1), it would follow that helium were the heavier of the two constituents.

This conclusion is supported by the following considerations: It was long ago noticed by Lecoq de Boisbaudran and has since been confirmed, that in the spectra of elements which are chemically related the series of lines are shifted to the less refrangible side with increasing atomic weight. This is the case with Li, Na, K, Rb, Cs, with Cu, Ag, with Mg, Ca, Sr, with Zn, Cd, Hg, with Al, In, Fl. On the other hand it appears that in the order of their atomic weights in the same row of the periodic system, the series are shifted to the less refrangible side with increasing atomic weight; for instance, Na, Mg, Al; K, Ca; Cu, Zn; Rb, Sr; Ag, Cd, In. If we now assume that the atomic weights of the two constituents are between those of hydrogen and lithium, the supposition that helium is the heavier of the two constituents is in accordance with the fact that the three series of helium are shifted to the more refrangible side.

The hypothesis of the two constituents, thus far based upon a comparison of the line spectra of the elements, where "series" have been observed, is strengthened by the fact that it is possible to make vacuum tubes which show the three series of helium much less brightly, while the three series of parhelium have suffered a much smaller decrease in intensity; so that the capillary tube looks green instead of yellow, the line 5016 surpassing D_3 in brightness. We first made this experiment by inserting a plug of asbestos in the tube connecting the gas supply with the vacuum tube. When the current of gas was cut off after a sufficiently short time the vacuum tube appeared green. We explained this by assuming that one of the constituents had more easily diffused through the plug, and was therefore the lighter one. However, this inference is open to objection. The green tubes were filled with a smaller amount of gas, hence the pressure in them was smaller than the pressure in the yellow tubes. The difference in the relative intensities of the two systems might also be due to the difference in pressure. This we found to be the case. We connected the vacuum tube with a vessel of about twenty-five times its volume. The vessel could be filled with mercury in the same way as the globe of a mercury pump. Thus we could alter the pressure in the vacuum tube without letting any gas escape, and in a small direct-vision spectroscope we saw the lines 4472, 4713, 5876, 7065 decrease in intensity relatively to 4922, 5016, 5048, 6678, 7282, when the pressure decreased, and increase again when the pressure increased. It is therefore not proved that the diffusion through the asbestos plug alters the relative amounts of the two constituents. The phenomenon of the green and yellow tubes may also be explained by the difference of pressure alone. The diffusion experiment ought to be repeated with larger quantities of the gas, and the question whether the amounts of the two constituents are altered could then be tested by weighing. But, however, this may turn out, the fact remains that the lines when grouped according to the variations of their relative intensities fall into the same two systems that have been established by the comparison of the spectrum with the spectra of other elements. The lines whose intensities we compared were those easily visible simultaneously in a small spectroscope, but as the principal series of helium is not represented among them, it was thought necessary to compare the intensities of the two infra-red lines in the yellow and green tubes. Of these bolometric measurements an account is given at the end of this paper. The result was that while in the yellow tubes the helium line 11170 was on an average three times as strong as the parhelium line 20400, in the green tubes it was only 1.8 times as strong.

In the spectrum of the Sun's limb the stronger lines of the spectrum of clèveite gas had been observed and measured by Young long before this substance was discovered. To each line Young assigned a frequency number estimating the percentage of frequency with which the line was seen during six weeks of observation at Sherman in the summer of 1872. It is interesting to note that according to the frequency numbers the stronger lines fall into the two systems of helium and parhelium, the helium lines being always seen, the parhelium lines only about once in four cases. To the fainter helium lines the same remark does not apply, but we think it only likely that fainter lines may sometimes have been overlooked, though they were present.

HELIUM				PARHELIUM			
Runge and Paschen	Young	Frequency according to Young		Runge and Paschen	Young	Frequency according to Young	
4471.646........ 4471.858........	4471.8	100	25	4922.096	4922.3	30	8
4713.252........ 4713.475........	4713.4	2	2	5015.732	5015.8	30	10
5875.870........ 5876.209........	5875.98[1]	100	90	5047.816	5048.2	2	2
7065.48 .... 7066.00	7065.5	100	12	6678.37	6678.2	25	50

The case of 6678, which is far brighter than 7065 and 4472, and, nevertheless, has a much smaller frequency number, seems especially worthy of notice.

In the spectra of stars in which lines of helium and parhelium have been observed we could find no decided alteration in the relative intensities, except in the case of Nova Aurigae.[1] Here the parhelium lines 5016 and 4922 are among the strongest lines of the spectrum, while 4472 is faint and D_3 was seen only by Huggins, and also appears to have been faint. 6678, which also belongs to parhelium, was observed by Huggins[2] and possibly also at the Lick Observatory, but none of the other helium lines have been seen.

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[1] Rowland's determination. The values are quoted from Frost's translation of Scheiner, *die Spectralanalyse der Gestirne.*

In concluding, we may remark that we are well aware of the hypothetical nature of many of the arguments brought forward in this paper. Perhaps some time hence the theory of the oscillations that cause the series of lines may be discovered, and conclusions may then be drawn from them with certainty. We have not refrained from giving conclusions that rest on rather incomplete induction. But the attentive reader will have no difficulty in distinguishing fact from hypothesis.

ADDENDUM BY PROFESSOR F. PASCHEN.

The infra-red part of the spectrum could only be measured with instruments of the highest possible sensitiveness. I used the same spectroscopic bolometer employed in my former bolometric work. It consists of a bolometer and a prism of fluor-spar mounted on a spectroscope in which two concave mirrors have been substituted in place of the lenses of the collimator and telescope. The prism is automatically kept in the position of minimum deviation. The instrument has been standardized up to 9.429μ by means of a large concave grating.[3] This grating was made by Rowland especially for Langley's bolometric work and has comparatively few lines per millimeter. It was kindly lent by J. E. Keeler. The bolometer is double like Langley's. Each strip has a length of 7^{mm}, a width of $0^{\text{mm}}.25$ (equal to that of the slit and the image of the slit in the spectrum), a thickness of $\frac{1}{2000}^{\text{mm}}$ and a resistance of 8 ohms. The strips are made from Lummer-Kurlbaum's platino-silver foil and blackened on the etched side with the soot of a flaring petroleum lamp, the other side remaining bright. The mean current in the bolometer was made 0.02 ampères. The galvanometer I used is described in the *Zeitschrift für Instrumentenkunde*, January, 1893. The astatic system of magnets is constructed for high sensitiveness, the magnets being from 1^{mm} to $1^{\text{mm}}.5$ long. The coils were so connected as to give a resistance of 15 ohms. I worked mostly at night. The galvanometer needle executed but one double swing, and when in circuit with the bolometer of 8 ohms resistance took about 17 seconds to come to rest. The scale stood at a distance of 2.5 meters. Under these circumstances the galvanometer gave a deflection of 1^{mm}, with a current of 8.3×10^{-12} ampères, that is 120000^{m} for one micro-ampère. The sensitiveness of the bolometer in connection with the galvanometer described may be defined by stating that a deflection of 1^{mm} corresponds to a difference of temperature of 84×10^{-7} degrees Centigrade.

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[1] Many of the lines have been observed in the spectra of a large number of stars. See H. C. Vogel, *Sitz. d. K. Akad. d. W. Berlin*, 1895, p. 947; this JOURNAL, **2**, 333.

[2] See a letter to *Nature* on the subject. *Nat.* Oct. 2, 1895.

[3] For the determination of the wave-lengths a new curve of dispersion for fluor-spar, more accurate than that used in my former work, has been employed. The wave-lengths near 2μ differ slightly from those given by the former curve of dispersion published in *Wiedemann's Annalen*.

When undisturbed by air currents, vibrations of the floor, or variations of temperature the mean of three deflections reached an accuracy of 0.2^{mm}.[1] As an example of medium excellence I give the following series of measurements:

OBSERVATIONS MADE JULY 14, 10 A.M.

Fine tube showing nothing but the lines of clèveite gas with great brilliancy. The tube was arranged end-on, and an image of the narrow part was thrown on the slit by means of a silvered mirror which lengthened the image by astigmatism. The induction coil[2] was worked by six accumulators.

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[1] With some of the vacuum tubes this apparent accuracy was illusory, as induction currents seem to branch off through the bolometer in spite of careful insulation of the tube. This disturbance was principally felt with low pressure tubes.

[2] The one mentioned above as made and owned by Mr. E. Porter.

δ corr.	μ	Deflections		δ corr.	μ	Deflections	
		Single	Mean			Single	Mean
31° 31′.25	0.635	16.4 13.4	14.9	31° 3′.25	1.300	112.4 108.5	110.5
29 .25	0.656	29.5 30.0	29.8	1 .25	1.382	35.1 31.7	33.4
27 .25	0.680	48.7 55.0	51.9	30° 58′.25	1.512	11.1 6.8	9.0
25 .25	0.705	64.6 64.9	64.8	....	....	....	.....
23 .25	0.736	69.2 69.8	69.5	53 .25	1.730	27.8 23.4	25.6
21 .25	0.768	55.9 56.6	56.3	51 .25	1.814	27.4 33.2	30.3
19 .25	0.806	36.1* 37.6	36.9	49 .25	1.895	54.9* 49.6 52.3	52.3
17 .25	0.848	17.7 18.2	17.9	47 .25	1.979	68.5 69.8	69.2
15 .25	0.895	27.7 26.8	27.3	45 .25	2.060	76.7 77.5	77.1
13 .25	0.947	82.5 82.5	82.5	43 .25	2.140	69.8 68.8	69.3
11 .25	1.005	173.2* 183.5	178.4	41 .25	2.215	42.4 42.2	42.3
9 .25	1.070	238.8 233.0	235.9	39 .25	2.287	21.1* 18.0 22.4	20.5
7 .25	1.141	261.5 257.5	259.5	37 .25	2.362	8.0 8.6	8.3
5 .25	1.216	212.2 210.5	211.4				

The first column headed δ corr. gives the deviations of the arm carrying the bolometer. A correction is necessitated by the fact that the bolometric adjustment and the adjustment by eye do not exactly coincide. The column μ gives the corresponding wave-lengths. The third and fourth columns give the single deflections of the galvanometer and their mean. An asterisk signifies that the observation was disturbed. The curve of energy corresponding to these observations (Plate IV, Fig. 3), gave the following values for the places of three maxima:

δ =	30° 45′.34	31° 7′.44	31° 23′.64
wave-length =	$2^{\mu}.057$	$1^{\mu}.134$	$0^{\mu}.729$
intensity =	$77^{mm}.1$	$259^{mm}.5$	$69^{mm}.5$
proportional to:	1	3.37	0.901

Plate IV, Fig. 4 represents the spectrum of another vacuum tube provided with a window of fluor-spar, which also showed the spectrum of clèveite gas with great brilliancy. From 10^μ to $2^\mu.5$ there is a continuous spectrum, the energy curve showing only the inevitable absorption bands of water vapor and carbon dioxide. The cause of this spectrum is the heat radiated from the inner walls of the capillary glass tube. The maximum of this continuous radiation lies at about $\delta = 28^\circ\ 50'$, which corresponds to a temperature of about 150°C., supposing the radiant body to be lampblack. Sometimes the capillary tubes became hot enough to singe the piece of paper with which they were held. At $2^\mu.5$ the continuous spectrum becomes inappreciable, and a new spectrum begins, consisting of the three maxima already mentioned above, which, according to this measurement, have the following positions:

$\delta =$	$30^\circ\ 45'.94$	$31^\circ\ 7'.84$	$31^\circ\ 23'.40$
wave-length =	$2^\mu.035$	$1^\mu.119$	$0^\mu.734$
intensity =	$48^{mm}.7$	$129^{mm}.4$	$85^{mm}.3$
proportional to:	1	2.66	1.75

The last maximum is evidently the visible line 7282, to which light of the line 7065 is added on account of the small dispersion. As for the other two maxima, the formulæ of the two principal series give, when extrapolated, the values $2^\mu.04$ and $1^\mu.09$. The close coincidence of the maxima with these calculated values makes the identity appear very probable. A more stringent proof may be given by the following bolometric measurements. That the two lines belong to the spectrum of clèveite gas is proved by the fact that the height of the maxima increases and decreases with the brightness of the visible lines of clèveite gas. From Fig. 4 it may also be seen that there is no other maximum surpassing the energy of the heated glass, while, if a member of the first subordinate series of helium for $n = 2$ existed, its energy might be expected to surpass the energy of $2^\mu.04$, because 5876 surpasses 5016 in brightness. That one of the infra-red lines belongs to helium and the other to parhelium, is proved by the difference of their relative intensities in the yellow and green tubes. In the yellow tubes which show D_3 much brighter than 5016, the ratio of the intensities of the

PLATE IV.

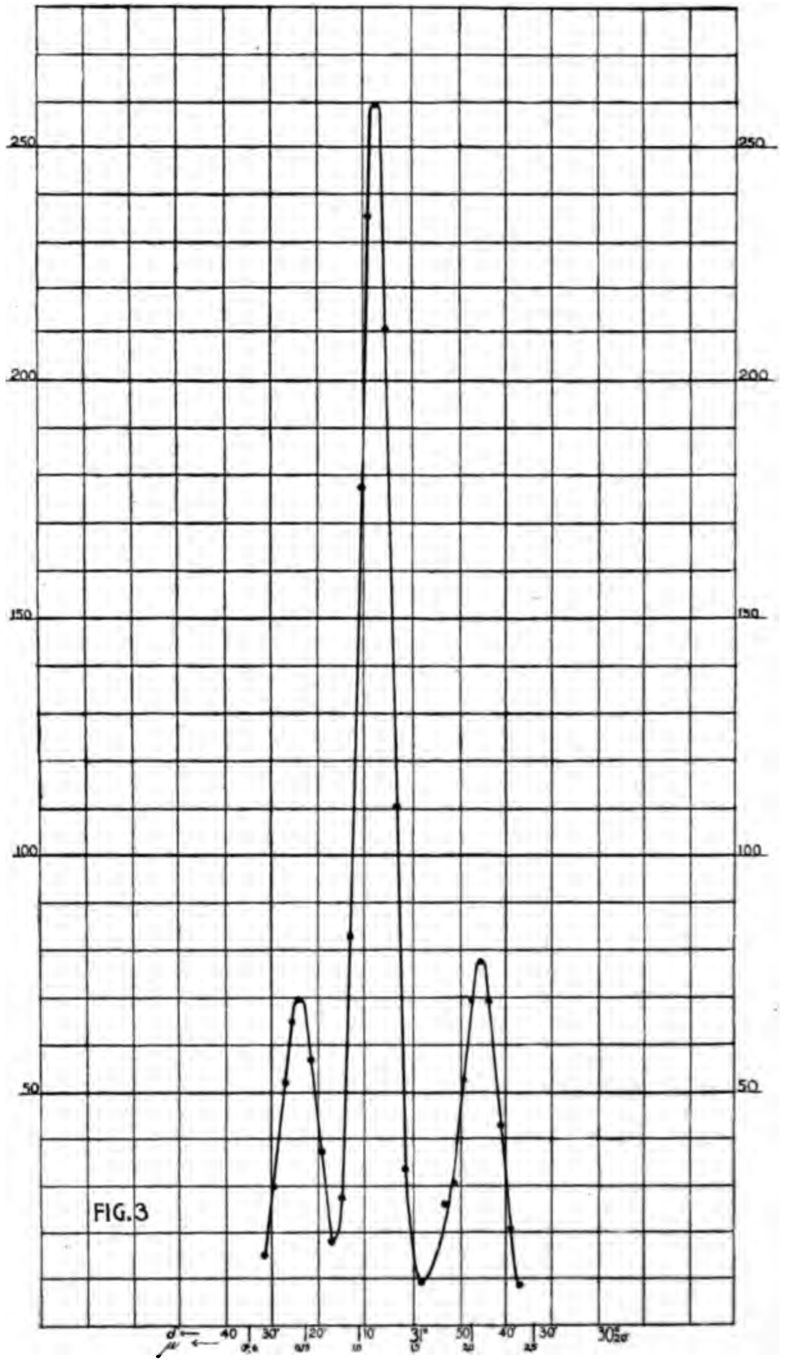

FIG. 3

PLATE V.

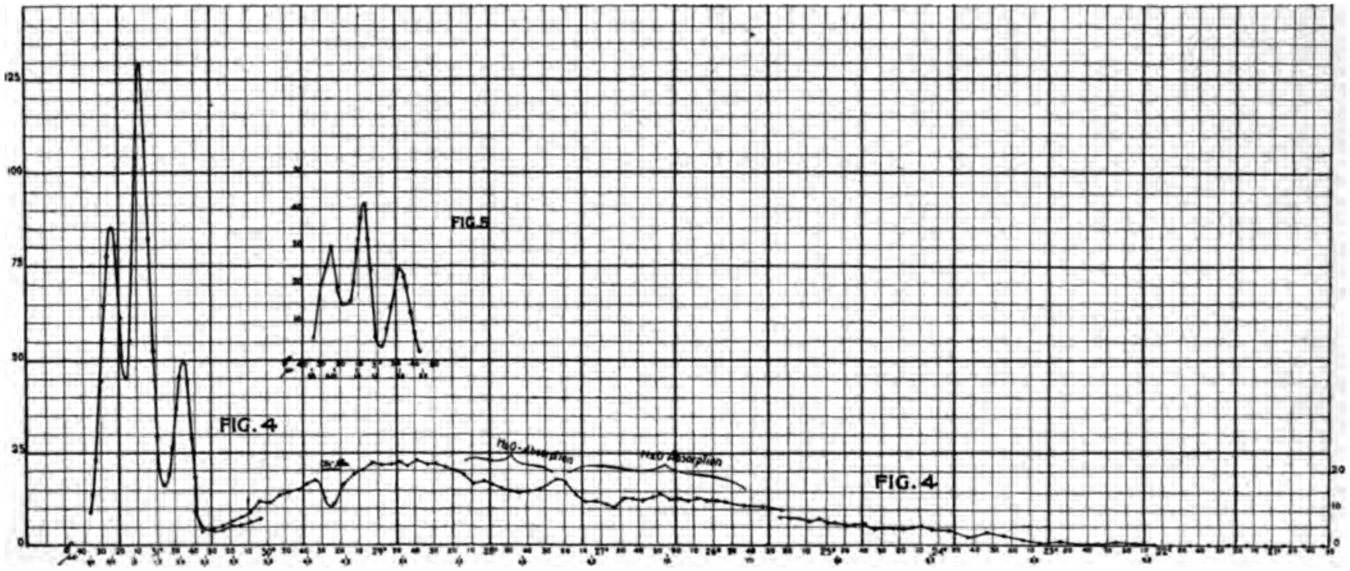

FIG. 4

FIG. 5

FIG. 4

Date, 1895	First Circle Reading	Maximum Height	Second Circle Reading	Maximum Height	Third Circle Reading	Maximum Height	Ratio of Heights	Remarks
		mm		mm		mm		
June 30	30°46'.34	20	31°9'.04	88.5	31°24'.24	25.1	1:4.43:1.26	Bright yellow tube closed with a quartz lens; showed no impurities. A second cylindrical lens collected the light on the slit.
July 1	46 .34	30.5	9 .74	101	24 .94	23	1:3.31:0.75	“ “ “ “ “ “ “
“ 2	44 .14	40.7	7 .14	140.7	....	....	1:3.46	Same tube as before; silvered mirror instead of cylindrical quartz lens.
“ 3	45 .54	38.6	7 .44	116.9	....	....	1:3.03	Tube with window of fluor-spar; silvered mirror.
“ 4	45 .99	41.3	7 .39	115.1	23 .44	68.9	1:2.79:1.67	“ “ “ “ “ “ “ “
“ 5	45 .94	48.7	7 .84	129.4	23 .40	85.3	1:2.66:1.75	“ “ “ “ “ “ “ “
“ 6	46 .64	42.7	7 .94	110.9	23 .64	80.0	1:2.60:1.87	“ “ “ “ “ “ “ “
“ 7	45 .84	43.2	7 .34	110.9	....	....	1:2.57	“ “ “ “ “ “ “ “
“ 8(I)	47 .94	26.5	7 .64	59.0	26 .24	45.7	1:2.23:1.73	Current stronger than usual Tube with quartz window, deteriorated; hydrogen lines strong, clèveite gas lines faint.
“ 8(II)	47 .44	9.9	8 .24	20.5	(24.44?)	14.8	1:2.07:1.50	Current as usual, 6 accumulators
“ 10	45 .44	27.3	7 .44	76.0	23 .14	50.1	1:2.78:1.83	Yellow tube with quartz window. Hydrogen lines visible.
“ 11 (I)	45 .34	26.1	7 .84	69.4	23 .44	48.6	1:2.66:1.86	The same, with current reversed.
“ 11 (II)	45 .34	24.0	7 .84	63.64	23 .44	46.5	1:2.74:1.94	The same, current again as on July 10.
“ 11 (III)	45 .24	26.2	7 .84	72.5	22 .94	54.9	1:2.77:2.10	The same as July (II), with instead of 6 accumulators.
“ 14 (I)	45 .34	77.1	7 .44	259.5	23 .64	69.5	1:3.37:0.901	6 accumulators. Best golden yellow tube; no impurities visible in a small direct vision spectroscope. Quartz window in tube.
“ 14 (II)	45 .24	74.5	7 .97	236.5	23 .64	71.8	1:3.17:0.964	6 accumulators, current reversed. Best golden yellow tube; no impurities visible in a small direct vision spectroscope. Quartz window in tube.
“ 14 (III)	45 .34	32.1	7 .39	106.0	23 .44	29.7	1:3.30:0.925	Current as on July 14 (II); 3 accumulators. Best golden yellow tube; no impurities visible in a small direct vision spectroscope. Quartz window in tube.
“ 15	47 .04	23.9	7 .79	41.8	23 .94	29.9	1:1.75:1.25	Tube with quartz window, recently filled through asbestos plug; green color (see description in the text); 5016 the brightest line in the visible spectrum. Hydrogen lines faint.
“ 19	45 .34	53.5	7 .92	142.5	23 .34	55.3	1:2.66:1.03	Large tube with 2 glass windows, recently filled through asbestos plug. Gas supply cut off later than on July 15, so that the tube already looked yellowish. Hydrogen lines faint.
“ 19	47 .04	8.0	8 .74	15.4	(20 .94?)	11.3	1:1.92:1.41	Small tube with quartz window, filled five days ago through asbestos plug; green color; showed 5016 about as bright as D_3. Hydrogen lines stronger. Measurement much disturbed and doubtful.
“ 24 (I)	44 .34	30.7	7 .49	113.7	23 .24	33.8	1:3.71:1.10	New golden yellow tube with quartz window. Hydrogen lines very faint.
“ 24 (II)	44 .89	45.0	7 .89	138.9	23 .44	49.4	1:3.09:1.10	The same, with current reversed.
Mean	30°45'.82		31°7'.88		31°23'.58			
m. e.	0'.204		0'.130		0'.191			

lines $2^{\mu}.04$ and $1^{\mu}.12$, varies between 1:2.2 and 1:4.4, and is generally 1:3.0. On the other hand, in the green tubes, in which 5016 equals 5876, or even surpasses it in brightness, the ratio was 1:1.75 or 1:1.92. The curve corresponding to a green tube is given in Plate V, Fig. 5. A comparison of the two lines in Fig. 3 or Fig. 4, with the same lines in Fig. 5, shows that in the green tubes the height of $1^{\mu}.12$ is about half its height in the yellow tubes, if $2^{\mu}.04$ is supposed to be of equal height in both. That $2^{\mu}.04$ is itself weakened in the green tubes is due to the pressure being so much lower than in the yellow tubes, which are so filled as to give maximum brightness. The above table contains the results of all the bolometric measurements of all the tubes examined. As quartz is sufficiently transparent for light down to $2^{\mu}.5$, the tubes provided with quartz windows could also be employed.

The means of the minimum circle readings and the means of the corresponding wave-lengths are:

δ	Mean Error of δ	Wave-length	Mean Error of Wave-length
30°45'.82........................	0'.204	$2^{\mu}.040$	0.0081
31 7 .88........................	0 .130	1 .117	0.0048
31 23 .74........................	0 .191	0 .728	0.0029

Why the relative intensities of the lines vary so considerably in the different yellow tubes and vary even in the same tube, when examined on different days, I am unable to explain, as vacuum tubes are difficult to control. Reversing the current also seems to produce a change, as may be seen from the table.

The two infra-red lines must also occur in the spectra of those stars in which the helium and parhelium lines have been observed. These stars must therefore radiate heat to us. That this has not been observed as yet may be due to the insufficient sensitiveness of the instruments employed.

K. TECHN. HOCHSCHULE,
Hannover, November 24, 1895.

ON THE NEW GASES OBTAINED FROM URANINITE.[1]

By J. NORMAN LOCKYER.

AS MR. CROOKES has now published[2] the wave-lengths of the lines in the spectra of the new mineral gases observed by him in the tubes supplied by Professor Ramsay, I propose in the present paper to bring together some notes I have made (some of them some time ago) on the same subject.

The researches made at Kensington in connection with the new gases obtained from bröggerite and other minerals have consisted, to a large extent, of comparisons of the lines in their spectra with lines in the spectra of the Sun and stars. Preliminary accounts of these comparisons have already been given, and they show that the bright yellow line seen in the gas from bröggerite is by no means the only important one which appears.

Although the general distribution and intensities of the lines in the gases from bröggerite and clèveite sufficiently correspond with some of the chief "unknown lines" in the solar chromosphere and some of the stars to render identity probable, it was desirable to see how far the conclusion is sustained by detailed investigations of the wave-lengths of the various lines.

The Yellow Line, λ 5875.9.—Immediately on receiving from Professor Ramsay, on March 28, a small bulb of the gas obtained from clèveite, a provisional determination of wave-length was made by Mr. Fowler and myself, in the absence of the Sun, by micrometric comparisons with the D lines of sodium, the resulting wave-length being 5876.07 on Rowland's scale. It was at once apparent, therefore, that the gas line was not far removed from the chromospheric D_3, the wave-length of which is given by Rowland as 5875.98.

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[1] Read before the Royal Society.

[2] *Chem. News*, August 23, 1895.

The bulb being too much blackened by sparking to give sufficient luminosity for further measurements, I set about preparing some of the gas for myself by heating bröggerite *in vacuo*, in the manner I have already described. A new measurement was thus secured on March 30 with a spectroscope having a dense Jena glass prism of 60°; this gave the wave-length 5876.0.

On April 5, I attempted to make a direct comparison with the chromospheric line, but though the lines were shown to be excessively near to each other, the observations were not regarded as final.

Professor Ramsay having been kind enough to furnish me, on May 1, with a vacuum tube which showed the yellow line very brilliantly, a further comparison with the chromosphere was made on May 4. The observations were made by Mr. Fowler, in the third order spectrum of a grating having 14438 lines to the inch, and the observing telescope was fitted with a high power micrometer eyepiece; the dispersion was sufficient to easily show the difference of position of the D_3 line on the east and west limbs, due to the Sun's rotation. Observations of the chromosphere were therefore confined to the poles.

During the short time that the tube retained its great brilliancy, a faint line, a little less refrangible than the bright yellow one, and making a close double with it, was readily seen; but afterwards a sudden change took place, and the lines almost faded away. While the gas line was brilliant, it was found to be "the least trace more refrangible than D_3, about the thickness of the line itself, which was but narrow' (Observatory Notebook). The sudden diminution in the brightness of the lines made subsequent observations less certain, but the instrumental conditions being slightly varied, it was thought that the gas line was probably less refrangible than the D_3 line by about the same amount that the first observation showed it to be more refrangible. Giving the observations equal weight, the gas line would thus appear to be probably coincident with the middle of the chromospheric line, but if extra weight be given to the first observation, made under much more favorable conditions, the gas line would be slightly more refrangible than the middle of the chromosphere line.

Pressure of other work did not permit the continuation of the comparisons. In the meantime, Runge and Paschen announced[1] that they also had seen the yellow line of the clèveite gas to be a close double, neither component having exactly the same wave-length as D_3, according to Rowland.

They give the wave-length of the brightest component as 5878.883, and the distance apart of the lines as 0.323.[2]

This independent confirmation of the duplicity of the gas line led me to carefully re-observe the D_3 line in the chromosphere for evidences of doubling. On June 14 observations were made by Mr. Shackleton and myself of the D_3 line in the 3d and 4th order spectra under favorable conditions; "the line was seen best in the 4th order, on an extension of the chromosphere or prominence on the northeast limb of the Sun. The D_3 line was seen very well, having every appearance of being double, with a faint component on the red side, dimming away gradually; the line of demarcation between the components was not well marked, but it was seen better in the prominence than anywhere else on the limb" (Observatory Note-book).

It became clear, then, that the middle of the chromosphere line, as ordinarily seen, and as taken in the comparison of May 4, does not represent the place of the brightest component of the double line, so that exact coincidence was not to be expected.

Though the observations are not yet quite completed, the circumstance that the line is double in both gas and chromosphere spectrum, in each the less refrangible component being the fainter, taken in conjunction with the direct comparisons which have been made, render it highly probable that one of the gases obtained from clèveite is identical with that which produces the D_3 line in the spectrum of the chromosphere.

Other observers have since succeeded in resolving the chromospheric line. On June 20, Professor Hale found the line to be clearly double in the spectrum of a prominence, the less refrangible component being the fainter, and the distance apart of the lines being measured as 0.357 tenth-meters.[1]

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[1] *Nat.* 52, 128.

[2] See their corrected values in an article published in this number of the ASTROPHYSICAL JOURNAL (Ed.).

The doubling was noted with much less distinctness in the spectrum of the chromosphere itself on June 24. Professor Hale points out that Rowland's value of the wave-length (as well as that of 5875.924, determined by himself on June 19 and 20) does not take account of the fact that the line is a close double.

Dr. Huggins, after some failures, observed the D_3 line to be double on July 10;[2] he also notes that the less refrangible component was the fainter, and that the distance apart of the lines was about the same as that of the lines in the gas from clèveite, according to Runge and Paschen.

It may be added, that in addition to appearing in the chromosphere, the D_3 line has been observed as a bright line in nebulæ by Dr. Copeland, Professor Keeler, and others; in β Lyræ and other bright line stars; and as a dark line in such stars as Bellatrix, by Mr. Fowler, Professor Campbell, and Professor Keeler. In all these cases it is associated with other lines, which, as I shall show presently, are associated with it in the spectra of the new gases.

The Blue Line, λ 4471.8.—A provisional determination on April 2, of the wave-length of a bright blue line, seen in the spectrum of the gases obtained from a specimen of clèveite, showed that it approximated very closely to a chromospheric line, the frequency of which is stated as 100 by Young.

This line was also seen very brilliantly in the tube supplied to me by Professor Ramsay on May 1, and on May 6 it was compared directly with the chromosphere line by Mr. Fowler. The second order grating spectrum was employed. The observations in this region were not so easy as in the case of D_3, but with the dispersion employed, the gas line was found to be coincident with the chromospheric one. In this case also, the chromosphere was observed at the Sun's poles, in order to eliminate the effects due to the Sun's rotation.

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[1] *A. N.* 3302.

[2] *A. N.* 3302.

In a former note,[1] I have pointed out that this line does not appear in the spectra of the gases obtained from all minerals which give the yellow line.

Besides appearing in the spectrum of the chromosphere, the line in question is one of the first importance in the spectra of nebulæ, bright line stars, and of the white stars such as Bellatrix and Rigel.

The Infra-red Line, λ 7065.5.—In addition to D_3 and the line at 4471.8, there is a chromospheric line in the infra-red which also has a frequency of 100, according to Young. On May 28, I communicated a note to the Royal Society stating that this line had been observed in the spectrum of the gases obtained from bröggerite and euxenite,[2] solar comparisons having convinced me that the wave-length of the gas line corresponded with that given by Young; and I added "it follows, therefore, that besides the hydrogen lines, all three chromospheric lines in Young's list which have a frequency of 100 have now been recorded in the spectra of the new gas or gases obtained from minerals by the distillation method."

M. Deslandres, of the Paris Observatory, has also observed the line at 7065 in the gas obtained from clèveite.[3]

Other Lines.—Determinations of the wave-lengths of many other lines in the spectra of the new gases have been made, chiefly with the aid of a Steinheil spectroscope having four prisms, and the results leave little doubt as to the coincidence of several lines with those appearing in the chromosphere, nebulæ, and white stars.

It seems very probable, also, that many lines which have been noted, and for which no origins have yet been traced, belong to gases which have not hitherto been recorded in the chromosphere.

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[1] *Proc. R. Soc.* **58**, 114.

[2] *Proc. R. Soc.* **58**, 192.

[3] *C. R.* June 17, p. 1331, 1895.

The following table summarizes the chief lines which have so far been recorded in the new gases from various minerals, some of which show D_3 while others do not. Only those lines which also appear in the spectrum of the chromosphere, nebulæ, or Orion stars, are given in the first instance. There are other lines which are probably also associated with chromospheric ones, but further investigation of them is considered desirable before they are included in the list.

The first column of the table gives the wave-lengths of the lines on Rowland's scale, while the second gives the wave-lengths on Ångström's scale; the third gives the frequency of the lines in the chromosphere according to Young. In the fourth column lines photographed with the prismatic camera during the total eclipse of April 16, 1893, are shown; these have been included because in some cases lines which appear to be comparatively unimportant in Young's list were photographed as important lines. The fifth column indicates probable coincidences with lines in the spectrum of the Orion nebula; the accuracy of these wave-lengths is of necessity less than in the case of the chromosphere; with the exception of D_3 they are taken from my paper on the photographic spectrum of the Orion nebula.[1] The sixth column shows probable coincidences with dark lines in the spectrum of Bellatrix, this being taken as an example of the Orion stars;[2] the lines 4922.3 and 5015.8 have been photographed since the date of the paper to which reference is made.

The last column gives the wave-lengths, from Mr. Crookes' table, of the lines observed by both of us.

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[1] *Phil. Trans.* **186A**, 76, 1895.

[2] *Phil. Trans.* **184A**, 695, 1893.

Wave-length (Rowland)	Wave-length (Ångström)	Chromo-sphere (Young)	Eclipse 1893. Max. intens. = 10	Orion nebula. Max. intens. = 6	Bellatrix. Max. intens. = 6	Crookes' measures
		Frequency	λR	λR	λR	λR
3888.7	3888.0	—	probable*	..	probable	3888.5
3964.0	3963.5	—	3963.8	..	3964.0(3)	3964.8
4026.5	4025.9	†	4026.0(6)	4026(3)	4026.0(6)	4026.1
4389.5	4388.5	1	4390.0(1)	4390(2)	4389.0(5)	4386.3
4471.8	4471.2	100	4471.8(10)	4472(4)	4472.0(6)	4471.5
4713.4	4712.5	2	4713.2(5)	4716(2)	4715.0(3)	4713.4
4922.3	4921.3	30	4922.0(4)	4924(3)	4922.0(2)	4922.6
5015.8	5015.0	30	5016.0(4)	..	5016.0(1)	5015.9
5048.2	5047.8	2	..	..	..	5047.1
5404.1	5403.1	5				
5429.9	5428.8	8				
5875.9	5874.9	100	5876.0	5876.0	5876.0	5876.0
5991.6	5990.0	15				
6065.7	6064.5	5				
6122.43	6121.43	5				
6141.9	6140.6	15				
6347.3	6346.2	10				
6371.6	6370.5	5				
6678.3	6676.9	25	..	..	..	6678.1
7065.5	7064.0	100	..	..	..	7065.5

† Professor Young has recently called attention to the fact that although this line was not included in his chromospheric list, he observed and published it in 1883; its frequency is about 15. (*Nat.* 52, 458.)

* This line is too close to a hydrogen line to enable a definite statement to be made.

OUTLINE OF AN ELECTRICAL THEORY OF COMETS' TAILS.

By Reginald A. Fessenden.

In a recent paper by J. J. Thomson, reviewed in the November number of this Journal, it is shown that carbon and hydrogen give different spectra according to whether they are positively or negatively electrified.

These results are at least suggestive when considered in connection with that phenomenon which we call a comet's tail. For, from the experiments of Hallwachs, Righi, Lenard and Wolf, and Elster and Geitel, we know that if an uncharged body be exposed to ultra-violet light the surface disintegrates, the particles produced fly off, carrying charges of negative electricity, and the body thus becomes positively charged though neutral before. Since the spectrum of the Sun is very rich in ultra-violet rays, we may state with some certainty that negatively charged particles are emitted from that side of a comet which faces the Sun, and that the comet's nucleus has a positive charge.

It has been observed that in the Sun's chromosphere the red line of hydrogen is brighter than the green, indicating according to J. J. Thomson's results, that the hydrogen in the Sun is negatively electrified.

The negatively electrified particles emitted from the comet's nucleus must therefore move under the influence of four forces: a force G due to gravitation, and acting toward the Sun; a force P due to the electrostatic repulsion of the negative charge on the Sun; a force Q due to the attraction of the positive charge on the comet's nucleus; and a force R due to the electrostatic repulsion of each negatively electrified particle for all the other similarly electrified particles.

Since observation shows that the shape of the tail (aside from certain irregularities revealed by photographs, which I have dealt with in another portion of this note), is such as would be produced by such forces, since, moreover, the tail gives the candle spectrum of carbon, and must, therefore, according to Thomson's results, consist of negatively electrified carbon particles, a certain degree of probability attaches to the theory which I venture to put forward:—that a comet's tail consists of negatively charged particles driven off from the nucleus by the action of the ultra-violet light of the Sun, and that its shape is the resultant effect of the four forces above mentioned.

The theory that the tail is due to an electrical effect is of course not new, having been suggested at an early date, and elaborated by Zöllner and by others. Their theories, however, are not definite, or postulate an electrical action proportional to the volume of the matter forming the tail, and two of the forces are omitted. Thomson's results, however, taken in conjunction with those of the above mentioned observers who have experimented upon the action of ultra-violet light, enable us, for the first time, to put forward the hypothesis with a certain degree of probability.

To produce the effects observed, the potential of the Sun need not be very high. According to Bredichin the repulsive force acting on a tail showing the candle spectrum is from $\frac{1}{10}$ to $\frac{1}{7}$ that acting on a tail which he supposes to consist of hydrogen. He did not, however, take into account the force Q due to the positive charge on the nucleus, and as this would be a comparatively larger component of the total force acting on the lighter tail, his results are too small. Unless therefore, we are prepared to postulate the existence of some substance lighter than hydrogen, we must suppose that each atom of carbon forming the heavier tail has one ionic charge on it, or acts as if it were monatomic. This is probable on other grounds. Therefore the total quantity of electricity on the atoms of one gram of carbon will be nearly 8000 coulombs.

If the comet is at a distance from the Sun equal to the radius of the Earth's orbit, the gravitational force per gram of matter will be approximately 0.57 dynes. From the mean of Bredichin's results for the carbon tail we have, electrical repulsion = 1.5 times gravitational attraction. Therefore if q be the quantity, in electrostatic units, of electricity on the Sun, we have (the specific inductive capacity of a vacuum being nearly unity),

$$.57 \times 1.5 = \frac{q \times 800 \times 3 \times 10^9}{(93000000 \times 160933)^2}.$$

Dividing the value of q so obtained by 14×10^{11} (the diameter of the Sun in centimeters, and therefore its electrostatic capacity), we get for the potential of the Sun 50 electrostatic units, roughly, or about 15000 volts. This figure is by no means improbably high; in fact, it is low compared with the differences of potential observable in our own atmosphere.

Some consequences of this theory may be worthy of mention. These are :

So long as the matter forming the tail is being given off, the positive charge on the nucleus is increasing. The resultant force acting on a particle of the tail, just after it has been emitted, will therefore finally become directed back again to the nucleus and the tail will form no longer. But if in this condition the nucleus approach the Sun, the forces G and P will increase, the force Q remaining constant. Therefore the resultant will change direction, and the tail will form once more, and become larger the nearer the comet approaches the Sun. This agrees with observation.

After a time, when the potential on the nucleus has increased to a certain amount, and the comet is at a certain distance from the Sun, the effect of the nucleus charge will preponderate, and the particles shot out will return to the nucleus. This appears to have been observed in the case of Coggia's comet.

The head of the comet must become smaller as it approaches the Sun, as the electrostatic repulsion P will then preponderate and cause the curvature of the first portion of the path of the particles to be much greater.

Owing to the great extremes of heat and cold to which the nucleus must be subjected, portions probably split off from time to time. Every such splitting must be marked by a sudden increase in the size of the tail, for if a spherical nucleus splits up into eight spherical portions each of half the radius of the original, the capacity will be quadrupled, and the total quantity being the same as before, the Q force will be less. This may account for the irregularities which have been observed in some tails, each irregularity corresponding to the splitting off of a fragment from the nucleus.

On the splitting up of a nucleus, new tails may be developed, for fresh surfaces will be exposed to the ultra-violet light, and elements which had been entirely driven off from the outside surface can now be acted upon. If the different parts of the nucleus clash against one another, we might expect to get the CO spectrum under such conditions.

If, however, a nucleus splits up, the chances are against the pieces remaining together. For example, if a 2 kilogram carbon nucleus splits up into two equal pieces, the gravitational attraction between the two will be $\frac{0.0665}{d^2}$ dynes, d being the distance between the two. But if each possesses a charge of 0.26 electrostatic units of electricity, the electrostatic repulsion would balance the gravitational attraction. Since the total quantity, as given above, on the atoms of one gram of carbon is 24×10^{12}, if the original nucleus had shed more than 10^{-14} grams of carbon as a tail, the two portions would be repelled from each other, and would gradually separate. This was observed in the case of Biela's comet, and generally it is probable that a nucleus which consists of more than one piece cannot hold together unless the fragments are very large.

Since the positive charge on the nucleus is continually increasing, the attraction between it and the Sun will be greater than that of gravitation, and continually increasing. This will have a similar effect to that produced by a resisting medium, *i.e.*, the period of the comet will be shortened. From the figures given above it will be seen that if a comet weighing one kilogram has used up one milligram in forming a tail, the resultant force in the direction of the Sun will be 1.0000015 times that due to gravitation alone. This retardation seems to have been observed in the case of Encke's comet.

On this theory a very remarkable effect should follow, in certain cases, the splitting up of a nucleus into two parts, but I should hesitate to mention it, had it not been observed in the case of Biela's comet. If a nucleus split up into two parts, *A* and *B*, *A* being the larger, then at first *B* will be the brighter. But the positive charge on *A* will attract the negatively charged particles of *B*'s tail, and if the other forces have the right magnitudes a portion of the tail will shoot out to *A* and neutralize a portion of its charge. Thereupon *A* will flash out brighter, until after a time, owing to *A* having its charge partly neutralized as fast as it forms, while the charge on *B* is steadily accumulating, *B* will become the more heavily charged and now a portion of *A*'s tail will shoot out to *B*, and the whole process will be reversed, to be repeated again and again as long as the conditions are favorable. Should this hypothesis prove true, a new importance attaches to the subject. For we may regard a comet as a gigantic electroscope, giving us the absolute electrostatic potential of the Sun, and possibly, by more refined observations, that of other heavenly bodies.

The presence of negatively charged hydrogen in the chromosphere cannot be considered as absolute proof that the Sun is negatively electrified as a whole, as the other ends of the lines of force may end on the Sun. The subject is one which the writer is unable to discuss. A number of theories might be advanced, but at present our knowledge on the subject is too small to render their consideration profitable.

WESTERN UNIVERSITY OF PENNSYLVANIA,
Allegheny, Nov. 30, 1895.

PHOTOGRAPHIC AND VISUAL OBSERVATIONS OF HOLMES' COMET.

By E. E. BARNARD.

THIS object was discovered by Mr. Edwin Holmes in London, on November 6, 1892, while endeavoring to find the Great Nebula of Andromeda with a reflecting telescope.

From several points of view it was one of the most remarkable comets ever observed.

At the time of discovery it was distinctly visible to the naked eye as a slightly ill defined star of the 6th magnitude. The remarkable fact that the comet had attained naked eye visibility when discovered, coupled with the further fact that this region must have been repeatedly swept over by comet seekers to within a few days of the discovery, shows that the comet must have rather suddenly attained its conspicuous visibility.

When found by Mr. Holmes this object was already some five months past perihelion ($T =$ June 13, 1892) and had been theoretically for several months in a far better condition for discovery.

From the care and skill shown by the large number of astronomers now engaged in comet seeking, there can be no doubt whatever but that this comet did not exist during that time with anything like one-tenth of the brightness it had at discovery.

From this, and its subsequent remarkable behavior, several astronomers argued that the object was not a comet in the true sense of the word, and that it must be the product of some celestial accident. This idea was further strengthened when its orbit was computed, and was found to lie within the asteroid zone. This orbit differed altogether from that of the ordinary comet by being almost circular.

According to the orbit the comet ought to have been easily visible at every previous opposition and should have been discovered long ago.

It seemed highly probable at least that it should be seen at its next opposition when it would be very favorably placed for observing. Though carefully searched for, no trace of the comet could be seen. The writer made a careful search for it both with the 12-inch and the 36-inch of the Lick Observatory, but without any success whatever.

From the fact that the orbit lay out among the asteroids Mr. Corrigan of Saint Paul and Dr. Daniel Kirkwood suggested that possibly two asteroids had collided and produced the phenomenon of a comet. However much faith may be placed in this hypothesis, I think, from the peculiar phenomena witnessed during the visibility of the comet, that it does not now exist in the cometary form, and furthermore, I do not think that it will ever be seen again, though it should return to perihelion in 1899. All the circumstances connected with it rather tend to show that it was of only a temporary nature.

The announcement of the discovery of this comet was received at the Lick Observatory on November 8, 1892, and it was observed that night with the 12-inch refractor. Its appearance was absolutely different from that of any comet I had ever seen. It was a perfectly circular and clean cut disk of dense light, almost planetary in outline. There was a faint, hazy nucleus with a slight condensation some 5″ south following the nucleus. With the naked eye the comet was just as bright, exactly, as the brightest part of the Great Nebula of Andromeda, near which it was visible.

At $8^h\ 0^m$ a careful estimate of its diameter made it 260″. At $9^h\ 40^m$ careful micrometer measures made the north and south diameter 286″.

On November 9, at $6^h\ 5^m$ the comet was brighter to the naked eye than the brightest part of the Andromeda nebula. At $6^h\ 20^m$ the measured diameter was 337″ north and south, with the 12-inch telescope; there was a faint diffused glow 12′ in diameter surrounding the comet symmetrically and a short, faint diffusion south following. The nucleus preceded the center about ½′ while at the center there was a slight condensation. With the naked eye at $8^h\ 0^m$ the comet looked like a small star and almost equal in brightness to ν Andromeda, and could not be distinguished from a star. At $8^h\ 30^m$ it was looked at with the 4-inch comet seeker—the diffused haze could be seen surrounding it with faint traces of a tail.

On November 11 it was observed with the 36-inch. The nucleus was found to be almost stellar and faint. A small star 20′ from the nucleus was shining through the comet. At $11^h\ 0^m$ it was observed and measured with the 12-inch; north and south diameter = 397″.

November 12. To the naked eye it was certainly less bright.

November 13. At $9^h\ 0^m$ the comet was certainly less bright and fading. At $11^h\ 45^m$, with the 12-inch the measured north and south diameter was 582″. It was less bright and not so definite.

November 14. With the 12-inch the comet was larger and fainter and more diffused. It was also fainter to the naked eye.

November 16. With the 12-inch the north and south diameter was about 10′. It was less dense looking, large and diffused and much fainter. At this observation there was nothing different in its appearance from the ordinary comet, except its size. There was an ill defined nucleus preceding the center and diffused brightening south following the nucleus. With a low power the comet was still fairly well defined. Several small stars could be seen shining through it. To the naked eye it was still stellar but fainter.

November 21. The comet was about 21′ in diameter and very diffused with a feeble brightening near the middle. To the naked eye it appeared much fainter than the Andromeda nebula.

November 24. At 8^h it was very large and diffused—at least 20′ in diameter.

December 5. The comet was not seen with the naked eye. In the 12-inch, by rapid sweeping with a low power, it appeared to be larger than the field of view (42′)—very large and vague.

January 4, 1893. It was excessively faint and large—indefinitely large; with a power of 150 on the 12-inch there was only the most excessively faint trace of the comet—a feeble glow extremely difficult to see.

January 16. Bad weather interfered with observations until January 16, when it cleared at dark. It seemed scarcely possible that the comet could be seen again, but from the importance of any positions of it, I thought it worth trying once more. The 12-inch was set for it, and upon looking in the telescope I was surprised to see a small, bright, hazy star. Thinking some mistake had been made, the telescope was again set only to find the same object. It seemed impossible that this star-like object could be the excessively faint and diffused nebulosity previously seen. Observations for motion, however, soon showed that it was in reality the comet.

Micrometer measures at $8^h\ 15^m$ made the diameter $29'$. It was of about the 8th magnitude and strongly condensed. In the finder, however, it appeared perfectly stellar and could not possibly be distinguished from an 8th magnitude star.

At $9^h\ 50^m$ the mean of two measures gave $32'.4$ for the diameter. At this time there had begun to appear in the condensation a small nucleus which had not been visible at first. It seemed to brighten rapidly while being watched, and soon became very distinct. At $10^h\ 20^m$ there was no question but that the nucleus was brightening; it seemed to form and become clear and distinct right before one's eyes.

At $10^h\ 30^m$ the 36-inch was turned upon the comet. It appeared very beautiful and remarkable in the great telescope. With this instrument its diameter was measured. The definiteness of the object may be inferred from the consistency of the measures.

$10^h\ 29^m$ diameter = $43'.4$
10 30 " 44 .9
10 31 " 43 .6

In the great telescope it looked exactly as it did on November 8 when first seen with the 12-inch. It was pretty well terminated and had a pretty bright nucleus. A few minutes later another set of measures was made of its diameter.

$10^h\ 42^m$ diameter = $47'.8$
" 47 .9
10 45 " 46 .0

The nebulosity was bluish, but the nucleus was hazy and yellowish and central. At $10^h\ 55^m$ there was a feeble glow about the comet, something like 1′ in diameter. Further measures were made with the great telescope.

$11^h\ 13^m$ diameter $= 47''.3$
11 15 " 46 .1

On this night there was no question whatever but that the nucleus actually formed in a few hours' time, while the comet was under observation; at the same time the body of the comet appeared to be expanding gradually.

January 17. At this date at $6^h\ 20^m$ the comet had a beautiful star-like nucleus. The nebulosity of the head surrounded it symmetrically, but was not bright. The diameter of this nebulosity was measured at $7^h\ 16^m$ and was found to be 46″, but because of its lesser brightness, the measures were not so certain. At 8^h the nucleus was very conspicuous—the nebulosity being very subordinate to it, the coma being merely a bright glow about the nucleus. The nucleus itself was yellowish and not perfectly stellar. At $8^h\ 20^m$ the comet and nucleus appeared like a star shining through fog. The nebulosity faded away softly from the nucleus which shone out conspicuously from it.

January 18. At $7^h\ 0^m$ the measured diameter was 89″ with the 12-inch. At $7^h\ 45^m$ the nucleus was difficult to see and was not brighter than the 13th magnitude.

January 19. With the 36-inch at $6^h\ 48^m$ the north and south diameter was roughly measured and = 121″. The nucleus was bright and there was no definite limit to the nebulosity.

January 20. With the 36-inch at $6^h\ 45^m$ the measured diameter was 136″. The nucleus was of the 10th magnitude and quite conspicuous, while the comet was much brighter in the middle. Taken altogether the object looked like a spherical mass of vapor, rounding up beautifully, with the nucleus shining in the middle.

January 22. With the 36-inch the comet was very diffused and was estimated to be 3′ or 3′.5 in diameter. At $7^h\ 30^m$ the nucleus was very indistinct and about 12th magnitude. There was a hazy glow close about the nucleus that seemed to partially hide it.

January 24. On the moonlit sky, the comet, in the 12-inch, appeared to be about 1′ in diameter—its greater portion being lost in the brightness of the sky. There was no nucleus. With the finder the comet appeared rather bright and cometary—like a large and conspicuous nebula.

After this, absence from the Observatory prevented the comet from being followed further.

These notes are condensed from those made at the times of observation, and show the remarkable transformations this object underwent. They may be useful sometime in aiding us to understand the nature of this remarkable body.

Photographs of the comet were made with the Willard portrait lens; the most interesting and important of these was the one made on November 10. An enlargement of this picture is herewith presented (Frontispiece).

So far as I can learn, this seems to have been the only photograph made of the comet in the first stages of its visibility.

The picture shows the well-defined outline of the comet and it also shows the faint diffused nebulosity seen surrounding it in the telescope.

There is one other thing that this photograph shows (and which seems to have been generally overlooked) that must sometime be of the highest importance in the solution of the mystery surrounding this extraordinary object. To the southeast of the comet, distant about one degree or so, is shown a large irregular mass of nebulosity covering an area of one square degree or more, and noticeably connected with the comet by a short hazy tail. Evidences of this diffused nebulosity had been seen when examining the region about the comet with a low power on the 12-inch. This very extraordinary appendage deserves the earnest attention of those who are at all interested in this comet.

KENWOOD OBSERVATORY,
December 14, 1895.

NOTE.—I find in examining the reproduction of this photograph, that the central, well-defined body of the comet has been lost in the half-tone, the outline shown being that of the diffused haze surrounding the comet proper. The nebulous appendage, however, is fairly well shown. E. E. B.

THE MODERN SPECTROSCOPE. XV.

By F. L. O. WADSWORTH.

IN the last number of the ASTROPHYSICAL JOURNAL I described a number of forms of "fixed arm" concave grating mountings which were designed with special reference for use as astronomical spectroscopes or in radiometric and interferential work for which the ordinary form of mounting is unsuitable. In calling attention to the great advantages which the concave grating possessed for astronomical spectroscopy[1] I pointed out that not the least important of these was its astigmatism, by virtue of which star spectra were broadened out into bands of a sensible width, making the use of a cylindric lens unnecessary in visual observation, and eliminating the danger of mistaking a defect in the film for a spectral line in a photographic record.

Valuable, however, as this property of astigmatism is in the case of stellar spectra, there is another class of astrophysical work in which it is most decidedly disadvantageous, and would indeed preclude the use of the instrument entirely if it could not be gotten rid of or overcome in some way. Reference is made not only to the direct visual comparison of spectra from different sources which is frequently desirable in identifying the lines in celestial spectra, but to two other quite as important problems: (1) the comparison, either visually or photographically, of the spectra from adjacent portions of the surface of the Sun or of the planets, for the purpose of determining the nature and extent of the reversals of lines in the Sun-spots, faculæ or prominences, or the displacements of the lines due to varying velocities of different portions of the surface in the line of sight; and (2) the formation and observation of monochromatic images of the whole or part of the surface for the purpose of determining, for example, the form of the prominences, either visually, through a wide slit tangent to the limb of the Sun, or photographically through the narrow moving slit of the spectroheliograph. For all of these purposes the concave grating offers the same advantages in the way of simplicity, accuracy and efficiency in light gathering power that it offers in other classes of work, but its astigmatism when used and mounted in the ordinary manner renders its employment in that way impossible.

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[1] At that time I did not know that the concave grating had ever actually been used on an astronomical telescope, but I have since found that it was used by Professor Crew (for the first time, I believe) on the Lick telescope in 1892. The mounting used by Professor Crew was the usual Rowland form, whose use was easily possible in this case because of the very short radius of curvature (only 22 inches) of the grating. Professor Crew points out clearly, not only the advantages referred to in my paper, but some others of almost equal importance, and speaks enthusiastically of the possibilities of the instrument in astronomical research. As he says at the close of his article: "The astronomical world is only just beginning to realize its indebtedness to Rowland for this instrument at once so beautiful and so powerful." See paper on "The Use of the Concave Grating for the Study of Stellar Spectra," by H. CREW. *A. ana A.* 12, 166, Feb., 1893.

In a paper published in *Astronomy and Astro-Physics* for November, 1894, Dr. Sirks[1] pointed out, for the first time, I believe, that in the first problem mentioned above, that of a direct comparison between two spectra from different sources, the effect of astigmatism may be avoided by placing the comparison prism which introduces the lateral beam, not against the slit of the spectroscope, but at a distance d from it which, in the case of the Rowland mounting, is equal to $\frac{\rho}{\cos i} - \rho \cos i = \rho \sin i \tan i$. Under these circumstances the spectral images have sharply defined edges corresponding to the edges of the prism, and may, therefore, be easily brought into coincidence. The same result may be secured by placing both of the sources, one just above the other, at the point indicated, or, better, since it would in general be inconvenient to then bring them into exact coincidence, by placing one of the sources at this point, and then forming the image of the other at the same point by means of a lens

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[1] "On the Astigmatism of Rowland's Concave Gratings." *A. and A.* 13, 763, Nov., 1894.

PLATE VI.

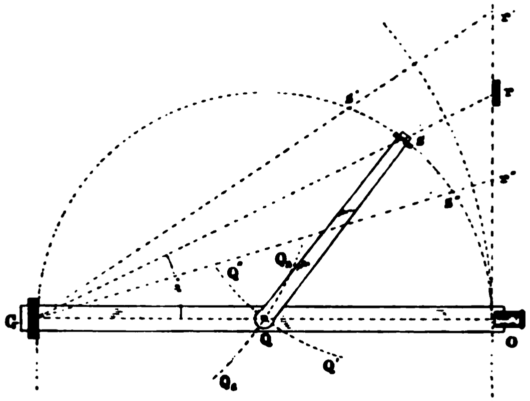


Fig. 1

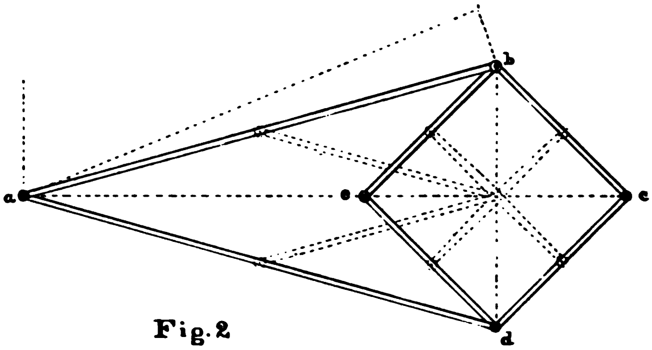


Fig. 2

Fig. 3

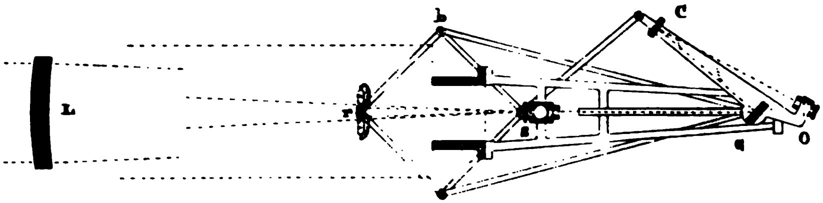
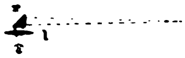


Fig. 4



or mirror. Then by adjusting the position of the image with reference to the first source the spectra may either be brought into coincidence or separated or made to overlap to any required degree.[1]

Although Dr. Sirks pointed out clearly the analytical conditions to be fulfilled for avoiding the effects of astigmatism, he suggested no form of mounting by which these conditions could be practically realized in the actual use of the grating. His method is manifestly impracticable, to say the least, if we are compelled to reset the source or the comparison prism by trial or measurement for every movement of the grating. The only alternative which presents itself is to fix this part of the system and move the whole grating mounting with respect to it, a method of procedure which it is practically impossible to adopt with the customary Rowland mounting, except, perhaps, for the very smallest sizes of instrument. But if we use a form similar to that shown in Figs. 12 and 13, Plate XVI. of the December number of this journal, the problem becomes less difficult, and is in fact susceptible of a very simple and satisfactory solution by means of a pure link work combination. Let G, Fig. 1, Plate VI., be the position of the grating, s the slit, r the source or the reflecting prism, and O the observing eyepiece placed normal to the grating and at a fixed distance, ρ, from it as in Rowland's mounting. Then in order to satisfy the conditions of a non-astigmatic mounting, the slit must lie always on the circumference of the circle $O\,s''\,s\,s'$ of radius $\frac{\rho}{2}$, while the source r lies at the intersection of Gs produced with the line Or, tangent at O to the circle of radius $GO = \rho$. For then

$$Gs = 2\,GQ \cos i = \rho \cos i$$

$$\text{and } Gr = \frac{\rho}{\cos i}, \text{ or } d = Gr - sr = \frac{\rho}{\cos i} - \rho \cos i.$$

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[1] It is of interest to note in this connection that when a condensing lens is used in front of the grating there is always one position of the grating in which dust particles, striæ, etc., on the surface of the lens will be in focus in the spectrum; a phenomena sometimes observed when the lens is dirty.

To satisfy the first condition it is simply necessary to mount the slit on the end of an arm of length $\frac{\rho}{2}$ pivoted at Q. To satisfy the second we must have from the geometry of the circle $Gs \times Gr = GO^2 = \rho^2 =$ Const. As is well known, this condition is satisfied by any inversor linkage[1] of which the two most simple forms are Hart's inversor and Peaucellier's cell, of which the last is shown in Fig. 2. This is the most suitable for the present purpose on account of its compactness and symmetry. In it we have $ae \times ac = ab^2 - be^2$, which to satisfy the above condition must equal ρ^2.

Hence, if we place the source or comparison prism at the vertex c of this cell and pivot the other two vertices e and a to the ends s and G of the links Qs, QG, respectively, the desired geometrical conditions will always be fulfilled and we obtain the simple and symmetrical mounting shown in Fig. 3. We may then fix either the pivot at G, the pivot at s, or the pivot at r in position. If G is fixed, Q may also be fixed, in which case the eyepiece O also remains fixed, but the slit and comparison prism r slide along the line Gsr, while this line itself rotates about the pivot G. A simpler arrangement therefore is obtained by fixing either the pivot s or the pivot r, leaving Q free. Then the grating and comparison prism, or the grating and slit, slide along the bar Gsr, which remains fixed, and the point Q describes a curve $Q'QQ''$ (if s is fixed), or QQ_1Q_2 (if r is fixed), whose centers at any instant are at G and s. The eyepiece O will therefore describe a similar curve of twice the radius about G as a center, and in order to avoid this large range of motion, as well as the long arm GO, we may place a reflecting mirror at C, Fig. 3, between G and Q and return the diffracted rays to an eyepiece O placed near G, as in the mountings shown in Figs. 12 and 13, Plate XVI., of the article previously referred to.

Whether s or r may be more conveniently fixed in position depends on the nature of the comparison desired. If simply a comparison between two sources of light as a whole is wanted, and it is desirable that the spectra shall be as bright as possible, it is best to fix the slit in position and form an image of the source upon it by a condensing lens *L* placed beyond the comparison source or prism. If the comparison source is light and easily movable (a Geissler tube or a spark gap between metal poles, for example) both it and the comparison prism may be mounted directly on the pivot at *r* and moved in and out together. The comparison source may be placed either at one side of the prism as is usually done, or better, just below it and at right angles to the slit, as shown in Fig. 4, this last arrangement enabling the whole length of the tube to be utilized and interfering less with the light from the direct source. The best results will usually be secured when the light which falls on the comparison prism or mirror is made slightly convergent by a short focus lens *l* placed between the prism and the source. If it is desired to use the instrument as a compound spectroscope in conjunction with either a refractor or reflector, it would be best to put the comparison prism, source, etc., inside the telescope tube (as indicated by dotted lines in Fig. 3), the pivot at *r*, which supports them, passing through a slot in the tube and connecting with the links *rb*, *rd*, which of course remain outside. The telescope should be adjusted in right ascension (the slit being placed parallel to the motion in right ascension), until the cone of light from the star just grazes the edge of the comparison prism.

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[1] See Reuleaux's *Kinematics of Machinery*, and Ziwet's *Theoretical Mechanics*, Vol. I, Sec. 6.

This general form of mounting (slit fixed, comparison prism movable) is, as has already been stated, well suited to direct comparison of the two spectra from different sources, but if it is desired to compare the spectra from adjacent parts of the same source, for example, from a Sun-spot or facula and the neighboring photosphere, or from the equatorial and polar regions of a planet, it is necessary that the image of the source shall be formed not on the slit plate as before but at the pivot *r* in front of the slit.

Since the image could only be moved by moving the condensing lens by which it is formed, and since this would in general be inconvenient and in an astronomical spectroscope impossible, it is best in this case to fix the pivot *r* in position, the slit and grating sliding toward and from it. The use of the concave grating in this way brings out one thing to which attention has not yet been called, *i. e.*, that although the spectral images from different portions of the source are well defined in a vertical plane, the image of any particular horizontal element is the integrated effect of the whole of that element, and hence, if the different portions of the source differ from one another in a horizontal direction as well as vertically, it is necessary to limit the width of the image at *r* to that portion of the source across which the radiation is homogeneous by a second slit parallel to the regular slit at *s*. This of course cuts down the quantity of light which falls on the second slit and the grating, the loss being greater as the angle of incidence *i* increases, and thus detracts considerably from the usefulness of the instrument for this particular purpose, except in the case of very bright sources such as the Sun. This instrument has another characteristic which is of importance in the study of approximately monochromatic and homogeneous sources of radiation, like the solar prominences. On account of the integrating effect at right angles to the slit, which has just been mentioned, no direct images of such sources can be obtained, as with the ordinary spectroscope, by opening the slit, and we cannot, therefore, study the *forms* of the prominences by this method. On the other hand we can determine with great readiness the *average* variations in density and structure of the prominence either in altitude or along the limb. For the first purpose the prominence is brought upon the screen or diaphragm at *r* in the position shown in Fig. 5, Plate VII., in which the heavily shaded portions represent the surface of the screen upon which the image falls, $s_1 s_2$ the slit or rectangular opening on which the prominence falls, the dotted lines down its center indicating the position of the spectroscope slit *s*, which lies behind it. Each point in the height of the resulting prominence spectrum will then be derived from a corresponding

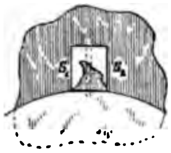

Fig. 5

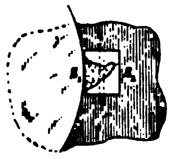

Fig. 6

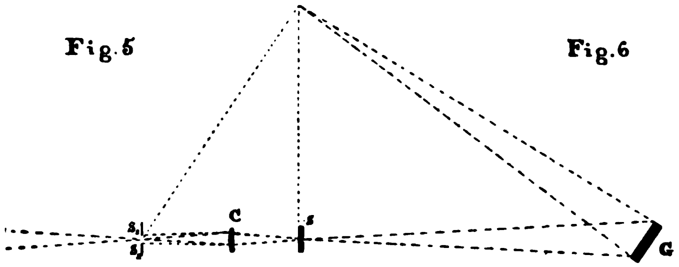

Fig. 7

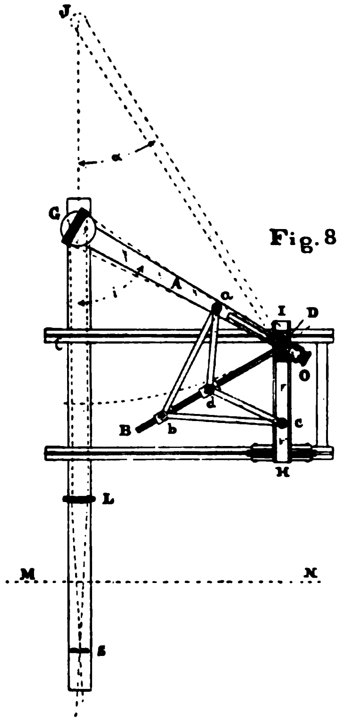

Fig. 8

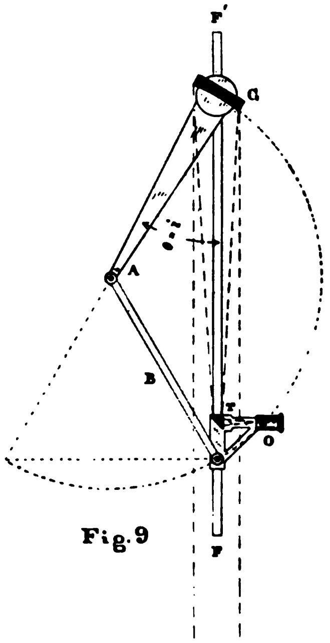

Fig. 9

horizontal or tangential strip across the prominence and will therefore have a width and position which depends on the average density of the prominence at that altitude and the motions, if any, in the line of sight. To analyze the prominence radially or along the limb, it must be brought on the first opening in the position in Fig. 6. In either of these cases we can utilize the light from the whole prominence and thus obtain a very bright spectrum by inserting a cylindrical lens *C*, Fig. 7, between the first opening $s_1 s_2$ and the slit s, the axis of the lens being parallel to the length of the slit and therefore without effect on the vertical definition of the source at $s_1 s_2$. This increase in brightness resulting from the use of the whole prominence without increasing the width of the slit may be of advantage also in studying the prominence spectrum as a whole, and may even enable the coronal line to be seen and studied without an eclipse.

A universal mounting of the preceding type which has recently been finished is shown in Plate VIII.[1] Its construction and method of operation will be readily understood from the preceding discussion and the following brief description. The slides are formed by two long rods of ¾ in. cold-rolled steel, which are supported geometrically on V's planed in three equidistant cross bars which are carefully aligned and leveled. Three geometrical slides carry the grating carriage, the slit and its accessories, and the comparison prism, with the attached Geissler tubes, etc. Any one of them may be geometrically clamped in position, the others remaining free. The long links, ab, ad of Fig. 2 are each 6 ft. 3 in. long and the short ones, be, ed, dc, cb, 3 ft. 9 in., allowing a range of motion from $i = 0$ to $i = 60°$ for which Gr or ac equals 10 ft. or $2\,\rho$. The vertices b, d of the cell are upheld by long, light, spiral springs attached to the ends of a cord which passes over a pulley fixed to the ceiling of the laboratory. The links themselves are of well-seasoned pine ½ in. by 1⅛ in., to the ends of which are screwed brass bushings working on accurately turned steel pins. As shown in the photograph, the apparatus is set up for use with an electric arc and Geissler tubes, the screen and prism carriage at *r* being fixed, and the grating and slit movable. The apparatus is also arranged so that the long links may be readily disconnected and the grating used in the usual way, the image of the source being formed directly on the slit *s*. The mounting in this case becomes the same as that figured in Plate XVI. of my last article. Finally, as there suggested, the link *B* connecting the end of the grating arm and slit, may be disconnected, a collimator placed on the Y's shown attached to the grating track just in front of the grating carriage in the photograph, and the plane mirror on the grating arm either replaced by a concave, or the eyepiece at *o* replaced by an observing telescope, thus making the mounting suitable for use with a plane grating or prism train. When used with the concave grating the adjustments are made in the same manner as with the ordinary Rowland mounting, the reflecting mirror being first removed and afterwards replaced and adjusted to return the diffracted rays to the eyepiece at *O*. The mounting has been finished only a short time, but so far has proved very satisfactory.

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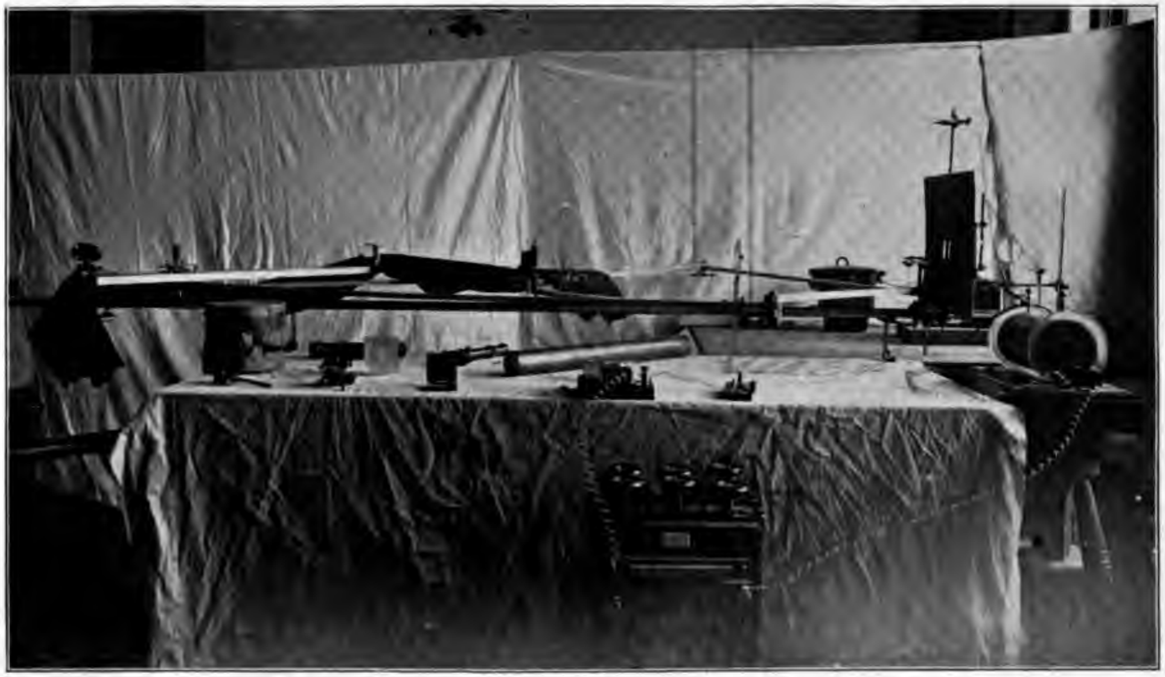
[1] The mounting is for a small five-foot grating kindly loaned to me by Professor Hale for these experiments.

The smoothness and ease of motion is especially apparent. For gratings of larger radius of curvature than 10 ft. the length of the links *a b*, *a d*, would become inconveniently great and it would therefore be desirable to modify the construction by bisecting all of the links of the system, as in the mounting of Fig. 13 of the Plate just referred to. This gives us the linkage shown in dotted lines in Fig. 2, which is evidently exactly equivalent to the linkage of Fig. 3, but is very much more compact as well as more symmetrical.

In the study of the subject of analyzing concave gratings another method of use has suggested itself which is so simple that it seems as though it must have been pointed out before, although I have not been able to find any mention of it in the papers of those who have written on the subject.

If we call *R* the distance of the source from the grating and

PLATE VIII.



F the distance from the grating to the point on its axis at which the source at R is well defined horizontally, then, as has been shown by Sirks,

$$\frac{1}{R}+\frac{1}{F}=\frac{1+\cos i}{\rho}$$

whence,
$$F=\frac{\rho}{1+\cos i-\frac{\rho}{R}}. \qquad (1)$$

On the other hand the coördinates of the point r, θ, at which the *spectrum* is in focus are given by the well-known relation

$$r=\frac{\rho\cos^2\theta}{\cos\theta+\cos i-\frac{\rho}{R}\cos^2 i};$$

when the point r lies on the axis of grating or $\theta=0$, this becomes

$$r_0=\frac{\rho}{1+\cos i-\frac{\rho}{R}\cos^2 i} \qquad (2)$$

and by comparing (1) and (2) we readily see that F becomes equal to r_0 for all values of i when $R=\infty$, or in other words, the visual and spectral foci of the grating coincide when the rays incident on the grating surface are parallel, as they would be if the grating were turned directly on a star or on the Sun. In the case of a star or planet this would be the simplest possible arrangement, the source being so small that the spectral lines will be well defined, but in the case of the Sun, which has an angular magnitude of nearly ½°, a different plan must be adopted, viz., that of using an intervening slit on which the solar image is formed and inserting a collimating lens or mirror between this slit and the grating, to render the rays again parallel. This has the disadvantage, it is true, of decreasing the simplicity of the grating train by the introduction of a lens or concave mirror, but it has the advantage over the first arrangement described of rendering the first screen or slit unnecessary, and enabling the spectra of successive points in a very narrow vertical strip of the Sun's surface to be compared just as in an ordinary plane grating or prism spectroscope, to which it is superior in that the observing telescope at least is rendered unnecessary.

From equation (2) we have for $R = \infty$

$$r_\circ = \frac{\rho}{1 + \cos i}$$

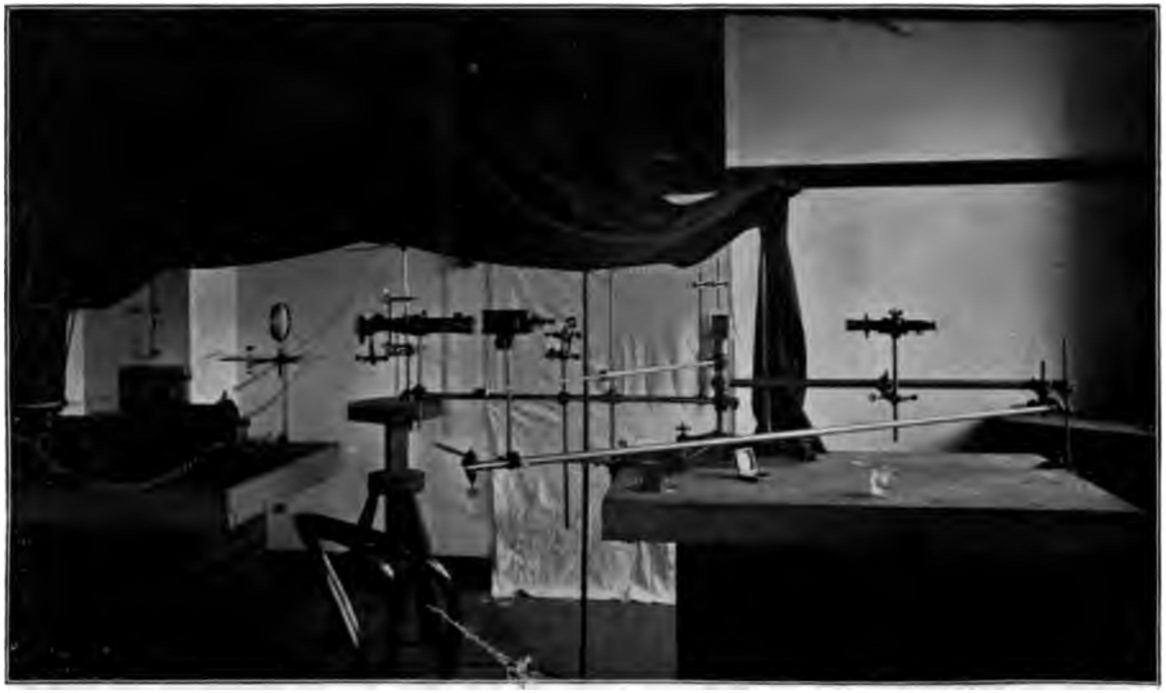
which is the polar equation of a parabola, the focus being the pole and the radius of curvature ρ being one-half the latus rectum. To keep the spectra in focus we must therefore move the eyepiece along the arc of a parabola of which the focus is the center of the grating, and the axis, the line of collimation $s\,L$, Fig. 8. This can be accomplished exactly by the link work mounting shown in Fig. 8, in which G is the grating mounted on the radius arm, GA, L the collimating lens and s the slit. The eyepiece O is mounted at the end D of an arm BD. The end D is pivoted to two slides, one of which moves along the track HI, parallel to the axis of the parabola, and the other in the radial slot in GA, normal to the grating; the eyepiece, therefore, always lies at the intersection of the center of the track and the axis of the slot. To keep this point of intersection on the parabola it is then only necessary to add the two pairs of equal links $a\,b$, $b\,c$, and $a\,d$, $d\,c$, whose outer ends are pivoted to $G\,A$ and $I\,H$ at equal distances, respectively, from the focus G and the directrix MN, and whose inner ends are pivoted to the collars b, d, sliding on $B\,D$; and mount the slide $I\,H$ on tracks parallel to MN. Then it is evident that as the track IH is pushed along, the distance of D from $M\,N$ must always remain equal to $G\,D$, since the arm $B\,D$ always bisects the angle $G\,D\,H$ and the triangles $a\,b\,D$ and $c\,b\,D$ are therefore similar.

Further, the arm $B\,D$ always lies along the tangent to the parabola at the point D, and hence, if a photographic plate is mounted with its length paralllel to $A\,D$ the spectrum will be in focus over the whole length of the plate.

The spectrum, however, will not be normal at D.

For we have from the theory of the grating—

PLATE IX.



$$\Delta\lambda = \frac{1}{nN}\cos\theta\,\Delta\theta = \frac{1}{nN}\Delta\theta.$$

But from the equation of the parabola we have

$$dr = \frac{r^2}{\rho}\sin i\,di = \frac{r^2}{\rho}\sin i\,d\theta;$$

and since $r\,d\theta = \sqrt{ds^2 - dr^2}$'

we get by substitution

$$d\theta = \frac{ds}{r\sqrt{1 + \left(\frac{r}{\rho}\sin i\right)^2}}$$

and $$\Delta\lambda = \frac{1}{nN}\,\frac{\Delta s}{r}\,\frac{1}{\sqrt{1 + \left(\frac{r}{\rho}\sin i\right)^2}}$$

which expresses the variation in wave-length as we go along the focal curve.

The preceding motion is exactly parabolic for all values of *i*. But in the use of the grating *i* rarely, if ever, exceeds 60° and for this range the parabolic curve coincides almost exactly with the arc of the circle, drawn about *J*, Fig. 8, as a center. A much simpler mounting is therefore obtained by mounting the eyepiece on the end of the arm *J D*, this arm having a pin which engages with the slot in *G A*. The small variation from the true parabolic curve is readily compensated by sliding the eyepiece slightly in or out. In the case of a five-foot grating, the radius arm *J D* is about 65 in. long, and the variation from the true focal curve does not exceed 0.1 in. at any point up to $i = 60°$. A photographic reproduction of a mounting constructed on these lines is shown in Plate IX. Its construction and method of operation will be readily understood from the plate and from the preceding description. The telescope shown at the left of the plate is the collimator, and the small one at the right is for focussing the large one and for the preliminary adjustment of the grating to perpendicularity to the line of collimation. The only other adjustments required is to place the grating so that its center is on the axis of rotation (accomplished very conveniently by rotating the grating under a fixed point or microscope, just above the grating table), and so that its axis is parallel to the arm *G A* (accomplished by reflection of a candle flame placed near *D*). The performance of this mounting has also been very satisfactory, and it is hoped that some results obtained with it may be shortly ready for publication.

There is one modification of the third general case discussed in my preceding paper, viz., that in which the grating is simply rotated on its axis, the slit and eyepiece both remaining fixed; that deserves special attention in this connection because of the extreme simplicity and beauty of the solution under the condition that was assumed in the case just considered, that of a source of light at an infinite distance. Let us assume that the angle θ is made equal to the angle i, or that the angle ϕ in Fig. 4, Plate XIV. (*Ap. J.* December, 1895) is zero. Then the general equation (4) p. 375, becomes

$$R = \frac{\rho \cos i}{2 - \frac{\rho}{r} \cos i},$$

or

$$r = \frac{\rho \cos \theta}{2 - \frac{\rho}{R} \cos \theta}.$$

The mounting which satisfies these conditions will be very similar to those of Figs. 1 and 3, Plate XIII. But if we make $R = \infty$ we then obtain the very simple solution

$$r = \frac{\rho \cos \theta}{2}.$$

which shows that the spectra all lie on a circle of diameter $\frac{\rho}{2}$. To keep the spectra continually in focus at the eyepiece it is, therefore, only necessary to maintain the grating and eyepiece always on the circumference of a circle of radius $\frac{\rho}{4}$, and further (to maintain the condition of equality of angle of incidence and angle of refraction), keep the chord of the circle which joins them parallel to the incident light. This may be done by a Rowland mounting of just one half the dimensions usually employed for a given grating, the eyepiece being placed in the position usually occupied by the slit and the latter dispensed with. A more compact arrangement, designed on the lines of the mountings shown in Plate XVI. (*Ap. J.* December, 1895), is shown in Fig. 9, where G is the grating set perpendicular to the length of the first link A, and r and O the reflecting prism and eyepiece attached to a carriage pivoted to the end of the second link B. Either the eyepiece may be fixed and the grating made movable along the track FF', or, if the latter is very large and heavy, it may be fixed and the eyepiece carriage made movable. If the grating is of very long focus the links may be bisected, as already described, but even with a 21-foot grating the two links of this mounting would each be only a little more than five feet in length. The spectra are not normal but the law of variation along the tangent to the focal curve is somewhat simpler than in the case of the plane grating. We have, in this case,

$$\Delta\,\lambda = \frac{2}{nN}\cos\theta\, d\theta\,.$$

But

$$d\theta = \frac{ds}{r}\cos\theta = 2\,\frac{ds}{\rho}\,;$$

$$\therefore\ \Delta\,\lambda = \frac{4}{nN\rho}\cos\theta\,\Delta s.$$

But if we set the eyepiece with its axis parallel to the direction of the diffracted ray, the spectrum in the field of the eyepiece becomes normal. For if D be the distance through which the micrometer moves for one division in the head, we have for the relation between this distance and the projected distance on the arc of the circle on which the spectrum lies

$$D = ds\cos\theta \text{ or } ds = \frac{D}{\cos\theta}\,.$$

$$\therefore\ \Delta\lambda = \frac{4\,D}{nN\rho}\,.$$

as in the ordinary mounting.

Similarly in the case of photographs we could obtain normal spectra by projecting each photograph on another plate at an angle θ with the first.

This mounting is astigmatic and is not therefore suited to the purposes for which the preceding forms have been designed. But it would seem particularly well adapted for a direct stellar spectroscope used without a telescope, both on account of its simplicity and compactness and on account of this very property of astigmatism which is, as has already been pointed out, a decided advantage for stellar spectroscopic work.

In order to secure sufficient brightness the concave grating would have to be larger than those now in use, at least as large as the objective of the telescopes now commonly employed for the compound spectroscopes, and it would therefore be best to fix the axis of the grating in position and make the eyepiece movable.

In this class of work it is, as has already been pointed out,[1] a decided advantage to also make the angular aperture of the instrument much larger than is usually done, not less than $\frac{1}{10}$ and preferably even $\frac{1}{6}$ or $\frac{1}{3}$. In the case of the concave grating, however, the effect of aberration increases as the cube of the aperture (when mounted in the usual manner) and even more rapidly when mounted in the manner just described.

With a 6″ concave grating of 21 feet radius of curvature this effect has been shown by Rowland to amount to less than one part in a million for extreme angles of diffraction,[2] and less than one part in 5000000 in the first spectra.

With a grating of an angular aperture of $\frac{1}{10}$ the effect would be between 125 and 150 times as great and with one of an angular aperture of $\frac{1}{6}$, 1000 to 1200 times as great. But since a very high degree of resolution is not necessary in the case of stellar spectra (the spectroscopes now commonly employed in this work have a resolving power, not usually exceeding 15,000 to 20,000), the ruling on these large gratings could be quite coarse (100 lines per mm. would give with a 30^{cm} aperture a resolving power of 30,000 in the first order), and the resulting angle of deviation small. It would moreover be best to use the first order spectra in order to best utilize the full grating aperture. The angle of deviation therefore would not need to exceed 5° to 10°, and the effect of aberration would therefore not be greater than one part in 20,000, even for an angular aperture of $\frac{1}{8}$, or just about the limit of the resolving power of the grating. But this may be still further reduced if necessary by slightly increasing the grating space as we go towards the edges, either by changing the step of the dividing engine or more conveniently by ruling the grating on a parabolic instead of a spherical surface. There is therefore no inherent difficulty in applying these large short focus gratings to such work, and the advantages which they would have over all other forms of stellar spectroscopes would well repay the preliminary difficulties which would be encountered in their ruling.

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[1] *Ap. J.*, January, 1895, **1**, 70.

[2] "Concave Gratings for Optical Purposes," H. A. Rowland, *Am. Jour. Sci.*, 3d Ser. **26**, 97.

It is also of interest to consider in this connection the question of the objective grating spectroscope or object glass grating. This instrument has recently been discussed by Jewell,[1] who has proposed a very ingenious method of making such a large transmission grating by photography. It would seem however that in the case of very large telescopes, the Lick and Yerkes, for example, this method would be impracticable because the plates upon which the grating is photographed would have to be of the same quality as the objective itself, otherwise the definition would be injured. The use of the plates might be avoided by photographing the grating directly on the surface of the objective, but this would be a process which would be attended with more or less danger and trouble, besides unfitting the objective for other purposes for the time being. Since the very large size of these instruments would necessitate only a very coarse ruling in order to obtain the necessary resolving power it would seem possible that the desired result might be very readily attained by the use of wire gratings made according to Fraunhofer's original plan of winding fine wire upon two parallel screws of very fine pitch. With a telescope of the size of the Yerkes a grating interval of $\frac{1}{10}$ mm. would be fine enough to obtain a resolving power of 10,000 in the first order, and it is perfectly easy mechanically to wind a grating of even twice this or twenty wires per mm. with suitable wire and suitable appliances. For $\frac{1}{10}$ mm. intervals comparatively large and strong wire (No. 38 American, or 40 B. W. G.) could be used, and the danger of any injury to the grating in handling thus minimized. Such a grating would also be comparatively inexpensive and very useful in the preliminary study of types of stellar spectra preparatory to the use of the great compound spectroscope to be provided for this instrument.

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[1] "The Object Glass Grating," *A. and A.* 13, 44, January 1894.

UNIVERSITY OF CHICAGO.
November, 1895.

MINOR CONTRIBUTIONS AND NOTES.

RECENT RESEARCHES BEARING ON THE DETERMINATION OF WAVE-LENGTHS IN THE INFRA-RED SPECTRUM.

THE relation between the refractive index of a substance and the wave-length of the corresponding refracted ray is one of great interest in physics, not only on account of its bearing on optical theories of dispersion, but because it must be used by the investigator of obscure heat spectra in order to determine the wave-lengths of rays observed with his prism of rock-salt or other diathermanous material. By means of photography the solar spectrum has been accurately mapped with diffraction gratings as far as $1^{\mu}.2$, and traced, with insufficient accuracy for measurement, to about $2^{\mu}.7$, but below this point the heating effect of the spectrum must be utilized. In general the grating cannot be employed in the investigation of these extreme wave-lengths, on account of its wastefulness; with specially powerful sources of radiant energy it can, however, be used to *calibrate* a prism, which then becomes available for wave-length determinations with radiant sources of moderate intensity. Other methods of calibrating a prism have also been devised which do not require the use of a grating.

Such measures in the invisible spectrum combined with visual or photographic observations of the Fraunhofer lines, allow a table to be constructed giving the refractive indices of the prism and their corresponding wave-lengths throughout a great range of the spectrum. A table of this kind, if made from reliable observations, is of great value for testing formulæ of dispersion. It also enables other observers who employ prisms of the same material to find at once the wave-lengths of the rays which they measure, and it therefore finds immediate application in all investigations relating to the laws of radiation by bodies at comparatively low temperatures. The present article gives an account of recent work of the kind indicated above, chiefly with reference to its value from the standpoint of the observer.

It is not necessary to specially mention the earlier investigations by which the measurement of rays in the lower spectrum was pushed to a considerable distance below its visible limit. All previous attempts in this direction were surpassed in 1884–6 by Professor Langley,[1] who, employing a large Rowland concave grating of short radius in connection with a rock-salt prism, and the electric arc as a source of radiation, measured the heating effect in the prismatic spectrum, by means of the bolometer, down to a wave-length of $5^{\mu}.3$. The curve for rock-salt, representing the index of refraction as a function of the wave-length, which he was enabled to draw by means of these observations, extends to this point, and its accuracy has been confirmed by all more recent investigations.

The main object of the observations was to determine the wave-lengths of absorption bands which had been discovered in the prismatic solar spectrum, but Professor Langley also used the material he had gathered to test a number of dispersion formulæ. Of these formulæ, which are deduced from theories founded on various assumptions as to the nature of the interaction between the ether and the molecules of the refracting substance, those of Cauchy and Briot are perhaps the best known. The former, in its shorter form, represents the dispersion in the visible spectrum with considerable accuracy, and is much used for interpolating wave-lengths when the intervals are short, even where great precision is required. Langley's method of testing was to determine the constants in the formulæ from observations of lines in the visible spectrum, and then to compare extrapolated values in the infra-red with the values deduced from his measurements. The result was that none of the formulæ were satisfactory. A similar test of dispersion formulæ by Brühl[2] led to the same conclusion.

To such methods of procedure Ketteler[3] has objected strongly. All the observations are necessarily affected with errors, which in some cases may have a great influence on the form of the curve determined from them, and the greatest care must be taken to employ reliable pairs of values of n and λ. In the tests mentioned above it does not appear that the points were always well selected, and a formula representing $n = f(\lambda)$ with erroneous constants derived from faulty values cannot be expected to represent the true dispersion curve. Ketteler's more circumspectly performed extrapolations are much more successful, but he regards the question as having little physical interest. His own formula

[1] S. P. Langley, *Mem. Nat. Acad. Sc.* 1883. *Ann. Chim. et Phys.* (6) **9**, 433, 1886.

[2] J. W. Brühl, *Liebig's Ann. der Chemie*, **236**, 233, 1886.

[3] E. Ketteler, *Wied. Ann.* **30**, 299, 1887.

(given further below in the present article), in which the effect of absorption on dispersion is taken into account, represents Langley's observations well, although the absorption of rock-salt is so slight that the test of the theory is not a conclusive one.

As Langley's measurements in the spectra of heated bodies extended below $5^{\mu}.3$, he sought to determine wave-lengths greater than this by a straight line extrapolation, continuing the dispersion curve by a tangent drawn at its lowest observed point, supposing that in this way at least minimum wave-lengths of the observed rays would be obtained. According to this process the wave-lengths of points at which heating effect could still be detected with a rock-salt prism exceeded 30^{μ}. The dispersion curve for rock-salt determined by Langley was adopted by Julius and by Ångström in their important investigations on the radiation and absorption by heated gases.

Not only were the instrumental means employed by Langley more powerful than those of his predecessors, but the method was distinctly superior to any that had been tried by them. The rays from the carbon of an electric arc fell first upon the grating, which was mounted on Rowland's well-known plan. The spectrometer, with rock-salt prism and train, was placed so that the spectrum of the grating fell upon its slit, through which therefore passed rays whose wave-lengths were known by the theory of the grating. By the prismatic train these rays were separated so as to form a series of images of the slit, each image belonging to a different order of grating spectrum, and their deviations by the prism were ascertained by means of the bolometer. In earlier investigations of wave-lengths the prism train had been placed first.

An entirely different method was used by Rubens[1] in 1892. The grating was dispensed with, and artificial cold bands of known wave-length were produced in a continuous spectrum, by interference. The positions of these bands, *i. e.*, their deviations by the prism, were measured by a linear bolometer. The interference was obtained by causing the rays from a zirconia burner, before they reached the spectrometer slit, to fall upon two plates of glass placed nearly in contact, so that the rays reflected from the inner surfaces pursued paths of slightly different length. By changing the distance between the plates, the intervals between the interference bands could be altered at pleasure. In some of the experiments the outer glass plate was replaced by a similar plate of fluorite.

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[1] H. RUBENS, *Wied. Ann.* **45**, 238, 1892.

The method of producing interference bands in a continuous spectrum had been previously used by E. Becquerel[1] for determining wave-lengths in his phosphorescent infra-red spectra, and by Mouton; but in these experiments the bands were produced by a plate of quartz between two polarizing prisms, and the spectrum was much weakened by the absorption of the apparatus.

Rubens determined the relation between the wave-lengths and refractive indices for glass, carbon bisulphide, quartz, water, benzol, fluorite and rock-salt, and platted the corresponding curves, which in most cases do not extend beyond $2^{\mu}.0$ or $2^{\mu}.5$. The curve for rock-salt, however, is given as far as $5^{\mu}.75$. It agrees closely with Langley's curve, and is nearly straight below 2^{μ}.

The curves for a number of the other substances exhibit some remarkable and interesting peculiarities. Those for xylol and benzol tend continually to a horizontal direction, as if they had an asymptote parallel to the axis of λ, like that required by Cauchy's formula. The curve for water has little curvature in the infra-red as far as $1^{\mu}.25$, where the observations stop. The dispersion therefore changes but little, throughout the whole range of the measurable spectrum. The curves for the other substances have points of inflection in the infra-red, beyond which the curves become concave toward the axis of λ; hence the dispersion, after diminishing to a certain point, again increases. This peculiarity, presumably the effect of absorption which is indicated by Ketteler's theory, seems to be here experimentally recognized for the first time. It is most noticeable in the case of glass, and does not appear at all, according to Rubens, in the curve for rock-salt.

The same method was employed by Rubens and Snow[2] in 1892 for determining the dispersion of rock-salt, sylvite and fluorite, but the apparatus was considerably improved. The plates for producing interference were larger ($4^{\rm cm}$ square) and the outer one was of fluorite; the optical train was composed entirely of fluorite and rock-salt, and the width of the bolometer strip was only $\frac{1}{12}^{\rm mm}$.

With this improved apparatus the curve for rock-salt was determined as far as $8^{\mu}.3$, but according to the measurements it was still convex toward the axis of λ, rising slightly above Langley's straight-line extrapolation. As these measurements seem to have been affected by errors, subsequently corrected, they need not be described further. The curve for sylvite is quite similar to that for the chemically related rock-salt, but the dispersion falls off more rapidly toward the infra-red. The curve for fluorite, which was traced with difficulty below $3^{\mu}.5$ as far as 8^{μ}, is very different from either of these. The reversal of curvature at about 2^{μ} is strongly marked, and the dispersion beyond that point is very great, nearly equaling, in fact, the dispersion in the visible spectrum. For this reason and for the practical one that its surfaces are permanent when exposed to the air, fluorite is particularly well adapted to the production of prismatic heat-spectra.

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[1] E. BECQUEREL, *Ann. Chim. et Phys.* (5) **10**, 5, 1877.

[2] H. RUBENS and B. W. SNOW, *Wied. Ann.* **46**, 529, 1892; *A. and A.* **12**, 231, 1893.

Compared with the method of determining wave-lengths, which was first described, the method of interference bands is inferior in a number of different respects. The bands have considerable width, and the minima are not sharply defined. Moreover, it is evident that if the band falls at a place where the distribution of energy in the spectrum is not uniform, the minimum heating effect will not be obtained when the center of the bolometer strip coincides with the darkest part of the band, but when it is displaced slightly toward the side of feebler energy. The error due to this cause becomes less, the narrower the bolometer strip which is used, but the uncertainties due to the breadth of the diffraction bands are not avoided by the use of a narrow strip. Methods of correcting the positions of the minima have been given by Rubens and Paschen. With Langley's apparatus, on the other hand, the maximum heating effect is obtained when the bolometer strip and the deviated image of the slit are in exact coincidence, provided their width is the same, whether the distribution of energy in the image is symmetrical or not. Hence a fairly wide slit and bolometer can be used without impairing the accuracy of the measures.

Carvallo,[1] by an ingenious modification of a method formerly used by Mouton, has succeeded in overcoming both the difficulties mentioned above. The diffraction bands are produced, as in the older method, by a plate of quartz between polarizing prisms; but the analyzer is double-refracting, and thus two complementary spectra are formed, one above the other, traversed by interference bands. A bright band in one spectrum is the prolongation of a dark band in the other. The narrow thermopile employed was placed across both spectra, and points were determined at which the heating effect on both ends was the same. The wave-lengths of such points are equally determinable by the wave-theory, and they are much more sharply marked than the minima. In this way Carvallo measured the dispersion of fluorite with considerable accuracy down to a wave-length of $1^{\mu}.849$, the absorption of the apparatus preventing any lower measures.

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[1] E. CARVALLO, *C. R.* 116, 1189, 1893.

In order to avoid the difficulties and uncertainties attending the transformation of prismatic into normal energy curves, F. Paschen[1] in 1893 attempted to measure directly the distribution of energy in grating spectra, the source of radiation being an incandescent carbon filament. In his apparatus lenses were avoided and reflectors were used. The result of many experiments with different gratings was, that the energy curves were always irregular; that some of these irregularities depended upon the grating, while certain well marked depressions were always found at the same places, no matter what grating was used or what other changes were made in the apparatus.

The cause of the irregularities first mentioned is now well known. An actual reflecting grating does not consist of alternate reflecting and absolutely black strips, as supposed in the elementary theory, but of a corrugated surface, all parts of which are capable of reflecting light. The theory of a grating with grooves of triangular section was worked out by Quincke in 1872, while the complete theory of gratings with grooves of various forms was given by Rowland,[2] who showed that under certain conditions not only were the different orders of spectra of greatly different intensities as compared with one another, but that the intensity might be far from uniform in any one order, so that a spectrum might, for instance, be strong in the red, and at the same time weak in the green. As Paschen remarks that physicists seem to have been of the opinion that a good grating can be relied upon to give a useful normal energy curve, it may be well to emphasize the fact that the ordinates of a grating energy curve depend upon a special peculiarity of the grating, as well as upon the nature of the radiant source.

It was remarked by Kayser and Runge,[3] in their work on the spectra of the elements, that with one of their large concave gratings the spectrum suddenly terminated at a certain wave-length in the ultra-violet.

The only explanation of the constant minima that Paschen could give was that they were caused by the absorption of gases in the air

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[1] F. Paschen, *Wied. Ann.* 48, 272, 1893, and 51, 1, 1894.

[2] H. A. Rowland, *A. and A.* 12, 189, 1893; *Phil. Mag.* 35, 397, 1893.

[3] H. Kayser and C. Runge, *Abh. d. K. Akad. d. W. Berlin*, III., 17, 1888.

(water vapor and carbon dioxide). It was necessary to suppose that the absorption was very strong, since varying the quantity of the two gases in the room did not appreciably affect its amount. Further experiments showed that it was impossible to obtain an unbroken energy curve, even with a prism, unless the air was carefully purified from carbon dioxide and water vapor. It was evident that large errors might be committed if an energy curve were determined by measurements at a few points in the spectrum, without taking these absorption minima into account, and their existence seemed to have been unnoticed by previous investigators.[1] Paschen gives the wave-lengths of the principal bands of CO_2 and water vapor, the values differing but little from those of K. Ångström, who used Langley's curve for rock-salt, and somewhat more widely from those of Julius.

The bands of Langley's infra-red solar spectrum are identified as follows:

Langley's ω at $1^{\mu}.4$ is water vapor.
" Ω " 1 .83 " "
" X " 2 .64 " "
" 2 .94 corresponds to band of liquid water.
" Y " 4 .6 is carbon dioxide.
" 5^{μ} to 11^{μ} corresponds to the strong water vapor absorption band with maxima at $7^{\mu}.1$ and $8^{\mu}.1$.

Paschen[2] attributes the discrepancies between his values for the wave-lengths of the atmospheric bands and those of Ångström and Julius to errors in the dispersion curves, particularly in the curve for fluorite. In the energy curve of Rubens and Snow several of the lowest observed interference minima nearly coincide with the absorption minima referred to above, and this is particularly unfortunate, since the lowest points are of great importance in determining the course of the dispersion curve. The probability of error in the curve is increased by the fact that the observers were unaware of the existence of these absorption bands.

This explanation is also accepted by Rubens,[3] who found it impossible to represent satisfactorily his earlier results, and those of Carvallo, with which they agree well, by Briot's formula. The method of artificial cold bands is defective in the extreme infra-red, not only for the reason pointed out by Paschen, but because the interference bands in that region have a great width (reaching 2½°), on account of the high dispersion of fluorite. On the other hand, the method is superior to Langley's in the upper spectrum, where there are no absorption bands, and where the minima are sharply defined. Rubens therefore redetermined the lower part of the dispersion curve for fluorite by Langley's method, using, however, a transmission grating of wire instead of a reflecting grating. The source of light was a zircon burner, and fluorite lenses were used in the optical train.

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[1] See, however, the note by F. W. Very, in this JOURNAL, 2, 237, 1895.

[2] F. PASCHEN, *Wied. Ann.* 51, 1, 1894.

[3] H. RUBENS, *Wied. Ann.* 51, 381, 1894.

The grating was made according to a peculiar, and perhaps novel method, which offers several features of interest. Two fine gold wires (about 0.03^{mm} in diameter) were wound together on a double rectangular frame. The wires were pushed together during the winding until no light was transmitted, and when the frame was full one of the wires was unwound. On securing the remaining wire in an appropriate manner, and separating the halves of the frame, two similar gratings were obtained, the definition of which was sufficiently good to permit optical settings to be made in the spectra of the fifteenth order. In general the spectrometer slit was set at random positions in the grating spectrum, but occasionally it was set on the D lines, as in the original method of Langley.

Measures were made with this apparatus down to $6^{\mu}.48$. It was impossible to go beyond this point for the following reasons: 1. The radiant energy of the zircon burner was too small, even when the slit was opened to 1^{mm}. 2. The definition of the spectral lines began to be bad in the high order of the spectrum in which the visual settings had to be made. 3. The chromatic aberration of the fluorite lenses required the readjustment of the draw-tubes of the spectrometer, this change introducing an additional source of error.

Rubens gives a table of the collected results, compared with computed values obtained by Briot's formula with constants given by Carvallo. The new and old measures fit well together, although there is evidence of a slight constant error where they join. The curve of Briot's formula agrees accurately throughout, and as Ketteler[1] has shown that it is also applicable to the ultra-violet, Rubens thinks there is no reason to doubt that it holds down to the beginning of the region of absorption, presumably at or below 9^{μ}. Extrapolated values of n are therefore given for 7, 8, 9 and 10^{μ}.

[1] E. Ketteler, *Wied. Ann.* 30, 299, 1887.

A paper in which Paschen[1] revises some of his wave-length determinations, using the new dispersion curve of Rubens, is largely devoted to a discussion of the bands of water and aqueous vapor, which is of much interest, although it does not immediately concern the present subject. Methods of correcting the observed positions of minima on the slope of an energy curve are also considered.

By further improving the apparatus already described, Rubens[2] was enabled to extend his measures in the spectrum of a fluorite prism down to 9^{μ}. No lenses were used in the optical train, and the width of the bolometer which was chiefly employed was only $\frac{1}{4}^{\mathrm{mm}}$, subtending an angle of $1'.5$ in the spectrum.

Combining with this additional material Sarasin's measures in the ultra-violet, Rubens forms a table containing pairs of values of n and λ for fluorite throughout the whole range of the spectrum, and uses it to test some of the more important dispersion formulæ. As two of these formulæ are much discussed in connection with this and subsequent work, it is desirable to give a short account of them here.

Briot's formula is

$$\frac{1}{n^2} = a + bl^{-2} + cl^2 + dl^{-},$$

in which l = the wave-length in the refracting substance $= \frac{\lambda}{n}$. The theory on which it is founded (Neuman's) assumes that the molecules of the substance are not set in vibration by the ether waves, and hence refers to perfectly transparent substances; therefore we cannot expect it to hold in the vicinity of a region of absorption, or to explain anomalous dispersion.

Ketteler[3] has deduced a formula from a theory which takes account of the sympathetic vibration of the molecules of the substance, and has shown that it can also be deduced from Helmholtz's electromagnetic theory of dispersion.[4] For two regions of absorption in the spectrum it takes the form

$$n^2 - a^2 = -\frac{M_1(\lambda_1^2 - \lambda^2)}{(\lambda_1^2 - \lambda^2)^2 + g_1^2\lambda^2} + \frac{M_2(\lambda^2 - \lambda_2^2)}{(\lambda^2 - \lambda_2^2)^2 + g_2^2\lambda}, \qquad (1)$$

in which the first of the terms on the right, for which $\lambda_1 > \lambda$, relates to an absorptive region in the infra-red, with strongest absorption at λ_1, and the second term on the right, for which $\lambda_2 < \lambda$, to a similar region in the ultra-violet with strongest absorption at λ_2. M_1 and M_2 are constants, and g_1 and g_2 are the so-called coefficients of friction in Ketteler's theory, appreciable only in the actual regions of absorption; g^2 is very small at a distance from these regions; if we neglect it Ketteler's formula becomes

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[1] F. PASCHEN, *Wied. Ann.* 52, 209, 1894.

[2] H. RUBENS, *Wied. Ann.* 53, 267, 1894.

[3] E. KETTELER, *Wied. Ann.* 49, 382, 1894.

[4] H. v. HELMHOLTZ, *Wied. Ann.* 48, 389, and 723, 1893.

$$n^2 - a^2 = -\frac{M_1}{\lambda_1^2 - \lambda^2} + \frac{M_2}{\lambda^2 - \lambda_2^2}. \qquad (2)$$

This approximate formula is represented by the four hyperbolic branches in the accompanying figure; between the points *a* and *b* it does not deviate appreciably from the complete formula represented graphically by the heavy line.

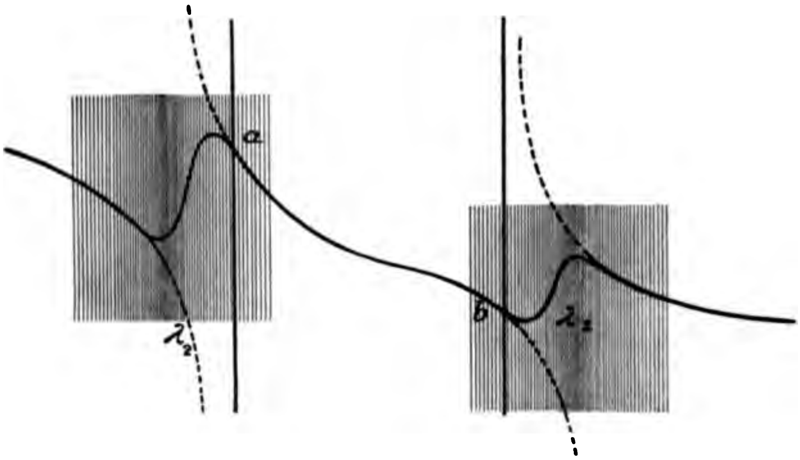

FIG. 1.

If (2) is developed, we obtain the equivalent series

$$n^2 - a^2 = -A - B\lambda^2 - C\lambda^4 - \ldots\ldots + \alpha\lambda^{-2} + \beta\lambda^{-4} + \ldots$$

Hence Ketteler's theory leads to ascending powers of λ^2 as well as to ascending powers of λ^{-2}. Ketteler usually tested his formula in the form

$$n^2 - a^2 = \frac{M_2}{\lambda^2 - \lambda_2^2} - k\lambda \qquad (3)$$

which much resembles Briot's, and found it equal to the latter for transparent substances. For less transparent substances another term must be added, giving

$$n^2 - a^2 = \frac{M_2}{\lambda^2 - \lambda_2^2} - k\lambda^2 - k_1\lambda^4. \qquad (4)$$

Rubens found that the values in his table were well represented by (3), as well as by Briot's formula.

Having calibrated his fluorite prism, Rubens used it to determine the relation between n and λ for prisms of various substances, by substituting it for the grating and allowing the rays from the zircon burner to pass successively through two spectrometers. On account of the imperfect surfaces of his rock-salt and sylvite prisms, Rubens could not measure the deviations of the visible lines very accurately, and it would seem that the definition in the infra-red must also have suffered. Accurate measures were possible in the case of glass and quartz. Some of the results, which are of much interest, are given below.

The flint glass used has a curve with strong inflection at $1^{\mu}.5$. The formula (3), with constants deduced from the upper spectrum, gives indices much too small in the infra-red.

With quartz (ordinary ray) the inflection is still greater, and the formula deviates widely beyond $2^{\mu}.3$. Even with constants determined from the upper red, (3) could not be made to satisfy the observations; (4) on the other hand, was satisfactory, and the region of greatest absorption according to it is at $\lambda_2 = 10^{\mu}.4$.

Rock-salt (compared with fluorite to $8^{\mu}.95$) also shows a distinct point of inflection, which is, however, not so strongly marked as in the other substances. The results agree with the previous determination by Rubens and Snow as far as 5^{μ}, but below that point there is a rapid deviation, errors already referred to having affected the earlier results. The constants computed by Ketteler from Langley's measures down to $5^{\mu}.3$, when used in formula (3) for extrapolation, give a fair agreement with Rubens' measures, which is still further improved by a slight change in the constants.

Sylvite also shows the inflection in the lower spectrum, its curve resembling that of the chemically analogous rock-salt. The new observations agree with the earlier ones of Rubens and Snow down to 5^{μ}. It is noteworthy that sylvite produces two remarkably sharp absorption bands in the infra-red, one at $3^{\mu}.20$ and the other at $7^{\mu}.08$.[1] Formula (3) represents the observations completely.

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[1] These wave-lengths are from a subsequent paper on the same subject.

The general result of Rubens' investigation is that formulæ (3) an (4) are verified by all the observations.

The dispersion of fluorite is also the subject of a paper by Paschen printed simultaneously with that of Rubens reviewed above. A bri history of previous determinations of infra-red wave-lengths is givei and the methods employed by Rubens are criticised. Paschen doub the excellence of Rubens' wire grating, and thinks that lenses shou not be used in such investigations.

In his own measurements, Paschen used a modification of Langle method. Lenses were avoided and mirrors used exclusively. T Rowland grating had 142.1 lines per millimeter, with a ruled surf 80^{mm} high and 132^{mm} wide, the radius of curvature being 1753^{mm}. T bolometer strip was $\frac{1}{4}^{mm}$ wide. With such a grating mounted acco ing to the well-known method of Rowland, the dispersion would h exceeded that of the prism fifty times, and the most important impro ment on Langley's method introduced by Paschen consisted in red ing the dispersion of the diffraction spectrum by a different arran ment of the grating until it was of the same order as that of t prismatic. In this way so great a saving of radiant energy was effect that a source of moderate intensity could be used. It was found th oxides have an extraordinary radiating power in the infra-red, partic larly oxides of iron. According to Paschen, a platinum strip coate with oxide of iron, and brought to a yellow heat, is nearly equal t white-hot carbon for the long wave-lengths, and it exceeds brigh platinum from ten to twenty times.

The results of a long series of measurements with this apparatu are exhibited in a table, giving corresponding values of n and λ. Th probable error of n for an assumed λ is only a few units in the fift decimal place,—certainly a remarkable degree of accuracy for mea ures in invisible heat spectra. On comparing the intensity and dispe sion at various points, it appears that with a fluorite prism the lon wave-lengths can be more accurately measured than the shorter on in the infra-red. The influence of absorption on the form of the low part of the dispersion curve was verified by independent measures the absorption of fluorite for rays of different wave-lengths.

By comparing the positions of the bands of water vapor in tl spectrum of his fluorite prism with the positions of the same bands

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[1] F. PASCHEN, *Wied. Ann.* 53, 301, 1894.

given by Julius for a rock-salt prism, Paschen[1] obtained an approximate dispersion curve for rock-salt down to $9^{\mu}.4$. The results agree with the later work of Rubens in showing a reversal of curvature in the infra-red.

With the data furnished by his wave-length determinations, Paschen[2] also tested the dispersion formulæ of Briot and of Ketteler. He does not agree with Rubens that the Briot formula represents satisfactorily the dispersion curve of fluorite. But on comparing computed values of n, employing constants derived from the upper spectrum, with the observed values, it was found that the deviation of the formula followed a simple law, and that agreement could be brought about by the addition of a term of the form el^4. The formula then becomes equivalent to Ketteler's, but it is to be noted that a term of this form cannot be derived from the older theory of Neumann.

Ketteler's formulæ (2) and (4) agreed excellently with the observations. In explanation of the different conclusion of Rubens that Briot's formula and (3) are competent to represent the dispersion curve of fluorite, Paschen considers that Rubens' measurements are slightly in error on account of the imperfections of his grating, and maintains the superiority of his own work.

The constants derived by Paschen for formula (2) are as follows:

$a^2 = 6.09104$ $\qquad M_1 = 5099.15$

$\lambda_1 = 35^{\mu}.475$ $\qquad M_2 = 0.00612093$

$\lambda_2 = 0^{\mu}.094256$

In replying to this paper, Rubens considers it probable that the discrepancies between his observations and those of Paschen are due to the differences between the gratings. The grating used by Paschen was no doubt superior to the wire grating used by himself. The discrepancies are, however, quite small. Accepting Paschen's values of n and λ below $2^{\mu}.5$, and retaining his own and Snow's above this point, Rubens readjusts his tables published in *Wied. Ann.* 53, 267, but the curves are not re-drawn, as their character is not altered by the scarcely perceptible corrections.

With regard to the capabilities of the formulæ, Rubens does not think it permissible to draw *a priori* conclusions from observed values of absorption. By slightly changing the previously determined values of the constants in (3), this formula also can be made to fit the new observations. The accompanying figure shows the dispersion curve for rock-salt, the small circles representing the values of n and λ from the table of Rubens, and the crosses the values which Paschen has derived from a comparison of his own observations with those of Julius.

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[1] F. PASCHEN, *Wied. Ann.* 53, 337, 1894.

[2] F. PASCHEN, *Wied. Ann.* 53, 812, 1894.

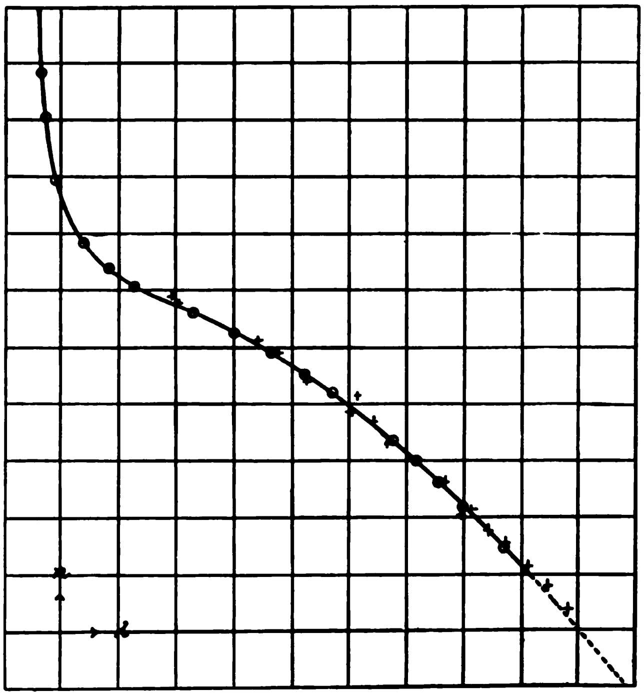

FIG. 2.

The smooth curve represents formula (3), with constants whose values are as follows:

$$a^2 = 2.3285 \qquad \lambda_2^2 = 0.01621$$

$$M_2 = 0.018496 \qquad k = 0.000920.$$

This is where the investigation stands at the present time. It is evident that a great advance has been made in our knowledge of infra-red wave-lengths. Although the results of the two principal investigators differ somewhat, they are in sufficiently good agreement to convince us that both are very nearly right. A knowledge of the dispersion of rock-salt is of fundamental importance in all researches on radiant energy in which this substance is employed, and this knowledge is now supplied by Ketteler's formula (3), with the constants given above, for all wave-lengths that there is usually any occasion to measure. Whether it has been definitely proved that Kettler's formula represents the true physical law of dispersion may be doubted, but it has been shown that the formula is a sufficiently close approximation to the law to answer all the practical purposes of observation.

One result of these researches must surprise those who have used rock-salt prisms. On account of the reversal of curvature of the dispersion curve, all wave-lengths formerly determined by extrapolation beynd 5μ are too large, and in case the extrapolation was an extensive one, very greatly too large. Thus the wave-length of the extreme rays measured by Langley and estimated by him at 30μ is probably not more than 15μ, or perhaps 10μ. It follows that the range of wave-lengths known to us is smaller than it was supposed to be a few years ago. JAMES E. KEELER.

HARVARD COLLEGE OBSERVATORY, CIRCULAR NO. 3.

NEW VARIABLE STAR OF THE ALGOL TYPE.

THE star *B.D.* + 17° 4367, mag. 9.1, whose approximate position for 1900 is in R. A. 20^h $33^m.1$, Dec. + 17° 56′, appears to be a variable star of the Algol type. On July 18, 1895, Miss Louisa D. Wells found that no trace of this star appeared on the photograph I 4359, taken with the 8-inch Draper telescope on September 26, 1891, exposure 16^m. On seventy-one other plates taken from June 30, 1890, to October 5, 1895, the star appears of its normal brightness. On December 12, 1895, at 10^h 42^m, Greenwich Mean Time, Professor Arthur Searle, who had watched this star on several nights, found it more than a magnitude fainter than usual. During the next half hour it diminished about half a magnitude more. Meanwhile, a photograph taken with the 8-inch Draper telescope, I 14036, confirmed the diminution in light. Unfortunately, at 11^h 15^m G. M. T., clouds covered the region, and the star, although carefully looked for, was not seen again that evening. The change in brightness appears to be rapid and the range of variation to be large, exceeding two magnitudes. The nearest bright star is *B.D.* + 17° 4370, mag. 7.0, which follows 14^s and is south 1′. The variability of *B.D.* + 17° 4370 has been suspected by Espin (*English Mechanic*, 62, 334), and also independently by Mrs. Fleming in 1890. EDWARD C. PICKERING.

December 13, 1895.

REVIEWS.

Recherches spectrales sur l'ètoile Altaïr. Reconnaissance d'un mouvement orbital et d'une atmosphère. H. DESLANDRES. *C. R.* **121**, 629–632, 1895.

The star α Aquilae has some spectral peculiarities which distinguish it from other stars of Vogel's class Ia, in which it is placed by Scheiner. Pickering noticed the uniform diffuseness of the lines, and Scheiner found that, in the region which he investigated, all the characteristic solar groups are faintly reproduced, so that the appearance is that of a faded solar spectrum. In a recent work on stellar spectra (*Pub. d. Astroph. Obs. zu Potsdam*, **7**, II, 232), Scheiner suggests, after considering an alternative explanation of the peculiar spectrum, that α Aquilae is a double star with components of the first and second class, and, although the Potsdam measures give no evidence of orbital motion, he advises that the star should not be lost sight of by spectroscopists. The same explanation, for composite first and second class spectra in general, was given by Pickering (*Ann. H. C. O.* **26**, I, xix.). An argument, which Scheiner justly regards as a strong one, in favor of the duplicity of α Aquilae, is the occurrence of the broad magnesium line at λ 4482, which is never strong in spectra of the second class, though almost invariably so in those of the first.

M. Deslandres, apparently without knowledge of these investigations, has found that α Aquilae is actually a double, or rather multiple star, by spectroscopic observations of its velocity in the line of sight. Fifty-six spectrograms, taken with the four-foot reflector of the Paris Observatory in 1892–5, show a large change of radial velocity with a period of 43 days, on which one or more smaller periodic changes are superposed. The observations are well represented by a secondary oscillation, of which the amplitude and period (about five days) are slightly variable. The star, therefore, should be at least triple; but M. Deslandres considers that a longer series of observations under more favorable circumstances will be necessary, in order to arrive at an exact knowledge of these complicated phenomena in all their phases.

The character of the metallic lines in the spectrum of α Aquilae, although it does not seem to have suggested to M. Deslandres the possibility of the multiple nature of the star, led to another discovery of much interest. It was pointed out by Deslandres some years ago, that bright lines should appear in the solar spectrum, under favorable circumstances, even with an integrating spectroscope. In fact, reversals of H and K, and perhaps some other lines, are found on Rowland's map. It was also pointed out that similar reasoning applied to the stars, and it was the breadth of the metallic lines in α Aquilae that led to its being selected as a test object. Deslandres finds that narrow double bright lines frequently traverse the middle of the dark lines of hydrogen, and sometimes even the lines of calcium and iron. With respect to the continuous spectrum they are of variable intensity. These lines Deslandres attributes to the star's chromosphere. His remark that Altair is the first star in which the special radiations of an atmosphere have been recognized, seems to require several qualifications, unless it can be shown that there is a sharp dividing line between such phenomena as those described above, and the appearances presented by the spectra of stars like φ Persei and Pleione.

J. E. K.

Spectrographische Untersuchungen des Saturnringes. A. BÉLOPOLSKY. *A. N.* No. 3313, **139**, 1–4, 1895.

In April and May, 1895, Herr Bélopolsky obtained a large number of spectrograms of Saturn with the one prism spectrograph of the Pulkowa Observatory mounted on the photographic refractor. The velocities of different parts of the system of Saturn were determined by measuring, not the inclinations of the spectral lines, but the absolute displacements of points on the lines at a measured distance from the center of the spectrum. The results, which agree well with those obtained at Allegheny, Mt. Hamilton, and Paris, are as follows:

Velocity of equator of Saturn	9.4^{km}	Computed 10.3^{km}.
Velocity of inner edge of ring	21.0	Computed 21.0^{km}.
Velocity of outer edge of ring	15.5	Computed 17.1^{km}.

J. E. K.

RECENT PUBLICATIONS.

AT the second annual meeting of the Board of Editors of THE ASTROPHYSICAL JOURNAL, recently held at the Harvard College Observatory, it was voted that an attempt be made to increase the scope of the bibliography of astrophysics and spectroscopy published under the heading "Recent Publications." In their present form the monthly lists of recent papers no doubt serve a useful purpose, though they make no claim to completeness. It is evident, however, that a bibliography which derives its titles mainly from the more accessible journals, the annals of the more important societies and the publications of observatories may be of no great value: it should also include publications of obscure origin. Papers of great importance frequently appear in the annals of the smaller societies, or are published at irregular intervals by institutions or individuals. In many cases but few copies of such papers are distributed, and consequently it sometimes happens that contributions of great value are overlooked for years.

It is now proposed that all who are interested in the formation of a complete bibliography of astrophysics and spectroscopy give their assistance by forwarding such titles as come to their notice. The bibliography is intended to cover all investigations of radiant energy, whether conducted in the observatory or in the laboratory. Special mention may be made of photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

To those who express themselves as willing to assist in this work cards conveniently arranged for the insertion of titles will be sent. These can be filled out, and mailed to the JOURNAL from time to time. Authors of papers are requested to send copies to Professors Hale and Keeler, in order that the titles may certainly find a place in the bibliography, and also for the purpose of review. If for any reason copies cannot be sent the title alone will serve for insertion in the bibliography.

The following list includes the serial publications from which the greater part of the titles now appearing in the bibliography are obtained. The abbreviated title is given in a parenthesis following the full title. Where none appears it is understood that the full title is to be used.

The editors will continue to index these publications, and the request for titles therefore applies only to papers not contained in them. This restriction does not include reprints of papers. These will be welcome, from whatever source they may be derived.

Papers, titles, or offers of assistance should be addressed to George E. Hale, Kenwood Observatory, Chicago, or to James E. Keeler, Allegheny Observatory, Allegheny, Pa.

Abhandlungen der K. Akademie der Wissenschaften zu Berlin (Abh. d. K. Akad. d. W. Berlin).
Abhandlungen der K. Bayrischen Akademie der Wissenschaften zu München (Abh. d. K. Akad. d. W. München).
American Chemical Journal (Am. Chem. Jour.).
American Journal of Science (Am. Jour. Sci.).
American Meteorological Journal (Am. Met. Jour.).
Annalen der Physik (Weid. Ann.).
Annales de chimie et de physique (Ann. Chim. et Phys.).
Annales ne l'école normale supérieure (Ann. école norm. supérieure).
Annuaire du Bureau des Longitudes.
Anthony's Photographic Bulletin (Anthony's Photo. Bull.).
Archives des sciences physiques et naturelles (Arch. de Genève).
Archives Néerlandaises des Sciences (Arch. Néerlandaises).
Astronomical Journal (Ast. Jour.).
Astronomische Nachrichten (A. N.).
Astrophysical Journal (Ap. J.).
Atti della R. Accademia di Roma (Atti d. R. Accad. di Roma).
Berichte der Deutschen Chemischen Gesellschaft (Chem. Ber.).
Berichte über die Verhandlungen der K. Sächsischen Gesellschaft der Wissenschaften in Leipzig (Ber. d. K. Gesell. d. W. Leipzig).
British Journal of Photography (Brit. Jour. Photo.).
Bulletin astronomique (Bull. Astr.).
Bulletin de l'académie impériale de St. Pétersbourg (Bull. Acad. St Pétersbourg).
Bulletin de l'académie royale de Belgique (Bull. Acad. R. Belgique).
Bulletin de la société astronomique de France (Bull. Soc. Astr. France.)
Bulletin de la société chimique de Paris (Bull. Soc. Chim. Paris).
Bulletin de la société impériale des naturalistes de Moscou (Bull. Soc. Nat. Moscou).
Chemical News (Chem. News).
Ciel et Terre.

Comptes rendus de l'Academie des Sciences (C. R.).
Electrician.
Elektrotechnische Zeitschrift (Elektrotechn. Zeitschr.).
English Mechanic (Eng. Mech.).
Engineering.
Himmel und Erde (Him. u. Erde).
Jahresbericht der Chemie (Jahresber. d. Chem.).
Johns Hopkins University Circulars (J. H. U. Circulars).
Journal de physique théorique et appliquée (Jour. de Phys.).
Journal für praktische Chemie (Jour. prakt. Chem.).
Journal of the British Astronomical Association (Jour. B. A. A.).
Journal of the Chemical Society of London (Jour. Chem. Soc. London).
Journal of the Franklin Institute (Jour. Franklin Inst.).
Knowledge (Knowl.).
Mathematische und Naturwissenschaftliche Berichte aus Ungarn (Be aus Ungarn).
Memoirs of the British Astronomical Association (Mem. B. A. A.).
Memoirs of the Royal Astronomical Society (Mem. R. A. S.).
Memorie della Società degli Spettroscopisti Italiani (Mem. Spettr. Ital.
Meteorologisches Zeitschrift (Meteorolog. Zeitschr.).
Monthly Notices of the Royal Astronomical Society (M. N.).
Nachrichten von der K. Gesellschaft der Wissenschaften und der Geor August Universität in Göttingen (Götting. Nachr.).
Nature (Nat.).
Naturwissenschaftliche Rundschau (Naturw. Rund.).
Nuovo Cimento.
Obers. K. Danske Vidensk. Selskabs. Forhandl. Kobenhavn.
Observatory (Obs'y.).
Philosophical Magazine (Phil. Mag.).
Philosophical Transactions of the Royal Society of London (Phil. Trans.
Photo-Beacon.
Photographic News (Photo. News).
Photographic Times (Photo. Times).
Physical Review (Phys. Rev.).
Popular Astronomy (Pop. Astron.).
Proceedings of the American Academy of Arts and Sciences (Proc. American Acad.).
Proceedings of the Cambridge Philosophical Society (Proc. Cambridge Phil. Soc.).
Proceedings of the Physical Society of London (Proc. Phys. Soc. London).
Proceedings of the Royal Institution (Proc. R. Institution).
Proceedings of the Royal Society of Dublin (Proc. R. Soc. Dublin).

Proceedings of the Royal Society of Edinburgh (Proc. R. Soc. Edinburgh).
Proceedings of the Royal Society of London (Proc. R. Soc.).
Publications of the Astronomical Society of the Pacific (Pub. A. S. P.).
Rendiconti dell' accademia delle science fisiche et matematiche di Napoli (Rend. R. Accad. di Napoli).
Rendiconti della R. Accademia di Roma (Rend. R. Accad. di Roma).
Report of the American Association for the Advancement of Science (Report A. A. A. S.).
Report of the British Association for the Advancement of Science (Report B. A. A. S.).
Science.
Séances de la société française de physique (Séances Soc. Franc. Phys.).
Sirius.
Sitzungsberichte der K. Akademie der Wissenschaften zu Berlin (Sitz. d. K. Akad. d. W. Berlin).
Sitzungsberichte der K. Bayrischen Akademie der Wissenschaften zu München (Sitz. d. K. Akad. d. W. München).
Sitzungsberichte der mathematische-naturwissenschaftliche Classe der K. Akademie der Wissenschaften, Wien (Sitz. d. K. Akad. d. W. Wien).
Sitzungsberichte der physikalisch-medicinischen Societät in Erlangen (Sitz. d. Phys. med. Soc. Erlangen).
Svenska vetenskaps Akademiens Handlingar (Svenska vetensk. Akad. Handl.).
Technology Quarterly (Tech. Quarterly).
Transactions of the Astronomical and Physical Society of Toronto (Trans. Ast. Phys. Soc. Toronto).
Transactions of the Royal Society of Dublin (Trans. R. Soc. Dublin).
Transactions of the Royal Society of Edinburgh (Trans. R. Soc. Edinburgh).
Verhandelingen der Koninklijke Akademie van Wetenschappen te Amsterdam (Verhand. K. Akad. Wetens. Amsterdam).
Verhandlungen der Schweizeschen Naturforschenden Gesellschaft (Verh. d. Schweiz. Naturforsch. Gesell.).
Verslagen van de Zittingen der Wis-en Natuurkundige Afdeeling van de Koninklijke Akademie van Wetenschappen te Amsterdam (Verslagen K. Akad. Wetens. Amsterdam).
Vierteljahrschrift der Astronomischen Gesellschaft (V. J. S. Astr. Gesell.).
Vierteljahrschrift der Naturforschenden Gesellschaft in Zurich (V. J. S. d. Naturforsch. Gesell. in Zurich).
Wilson's Photographic Magazine.
Zeitschrift für der physikalischen und chemischen Unterricht (Z. f. d. Phys. u. Chem. Unterricht).

Zeitschrift für Elektrotechnik und Elektrochemie (Z. f. Elektrotech. u. Elektrochem.).

Zeitschrift für Instrumentenkunde (Z. f. Instrum.).

Zeitschrift für Mathematik und Physik (Z. f. Math. u. Phys.).

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NOTICE.

The scope of THE ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

It is intended to publish in each number a bibliography of astrophysics, in which will be found the titles of recently published astrophysical and spectroscopic papers. In order that this list may be as complete as possible, and that current work in astrophysics may receive appropriate notice in other departments of the JOURNAL, authors are requested to send copies of all papers on these and closely allied subjects to both Editors.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. If a request is sent *with the manuscript* twenty-five reprint copies of each paper, bound in covers, will be furnished free of charge to the author. Additional copies may be obtained at cost price. No reprints can be sent unless a request for them is received before the JOURNAL goes to press.

The Editors do not hold themselves responsible for opinions expressed by contributors.

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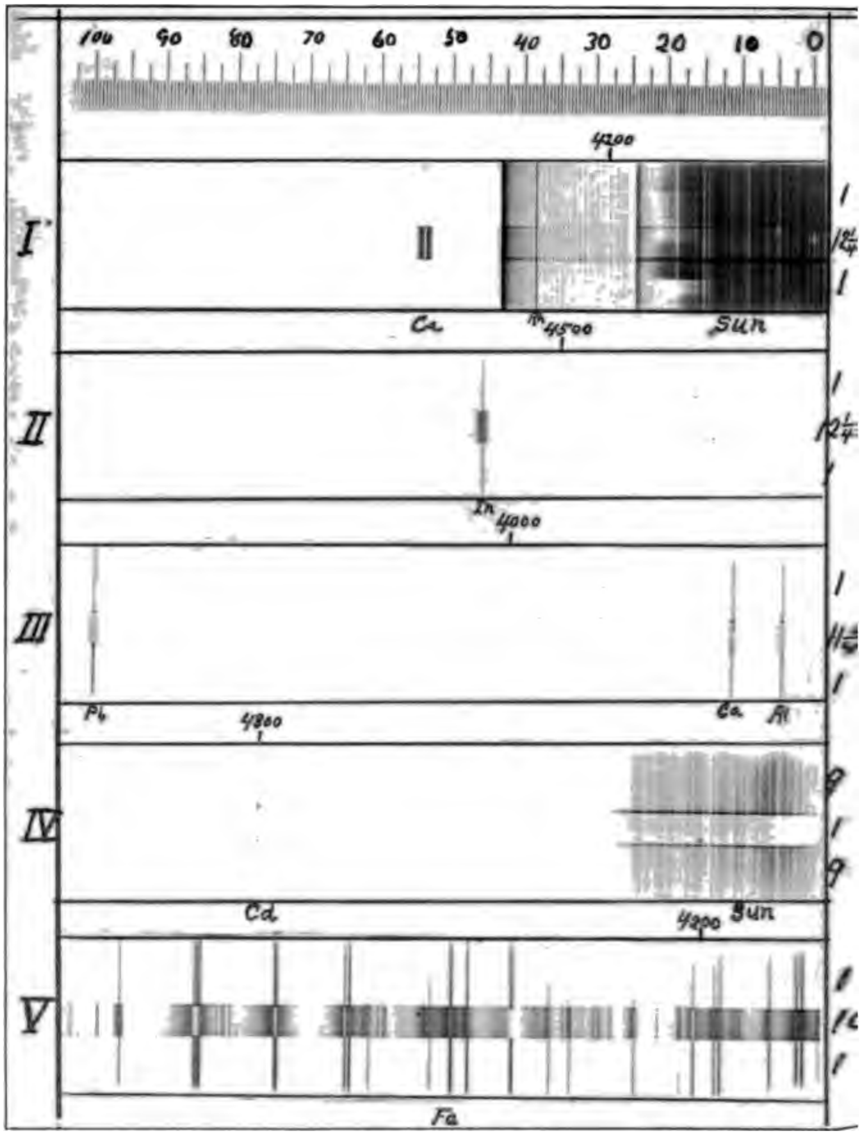
All papers for publication and correspondence relating to contributions and exchanges should be addressed to *George E. Hale, Kenwood Observatory, Chicago, Ill.*

PLATE X.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THE

ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOLUME III FEBRUARY 1896 NUMBER 2

THE COINCIDENCE OF SOLAR AND METALLIC LINES.

A STUDY OF THE APPEARANCE OF LINES IN THE SPECTRA OF THE ELECTRIC ARC AND THE SUN.

By L. E. JEWELL.

DURING the winter of 1890, while making the measurements upon which are based the values for the wave-lengths of the metallic lines in Professor Rowland's "New Table of Standard Wave-Lengths," I found that the metallic lines were almost invariably displaced toward the violet, when compared with the corresponding solar lines.

As Professor Rowland was not convinced that the displacement was due to any other cause than the accidental movement of the apparatus, when changing from the spectrum of the Sun to that of the arc, the displacement was treated as due to this cause, and the wave-lengths of all metallic lines corrected for the average displacement of the stronger " impurity lines" (generally iron) upon the plate, thus reducing them to an approximate agreement with the corresponding solar lines.

Knowing that the plates measured had been taken with the greatest care, I investigated the subject more carefully, and found that not only was the displacement nearly the same for the same lines, taken upon different plates, but that there was a distinct difference in the displacement, not only for the lines of different elements, but also for the lines of different character belonging to the same element.

Realizing that any movement of the apparatus could not produce a difference in the displacement for different lines upon the same plate, an explanation was sought for in the difference in the condition of the substances in the arc and the solar atmosphere.

The explanation that first suggested itself was that perhaps the Fraunhofer lines were produced by the absorption of cool gases descending in the solar atmosphere. This would mean a falling velocity of from twenty to forty miles per minute continuously over the whole solar atmosphere. This is not excessive when compared with the velocity of matter sometimes seen in the vicinity of Sun-spots, but it must be remembered that those are isolated cases, confined to limited regions, are seldom witnessed, and then only for a short time, while if the displacement of the solar lines is due to falling matter, it must occur over the whole solar atmosphere, and be kept up continuously. Furthermore, a downrush necessarily means a corresponding uprush. If the uprush were likewise of cool absorbing gases the solar lines would be considerably widened, while if the uprush were of highly heated gases, as would most probably be the case, all the lines in the solar spectrum would be paired, a bright with a dark line. As neither appearance is found it follows that generally the velocity of the gases giving the Fraunhofer lines must be slight.

The only explanation possible seemed to be that the observed displacement must be due to a difference in the conditions of matter in the electric arc and in the solar atmosphere. Almost the only possible differences are those of pressure or density of material and temperature, or both.

When the matter was carefully looked into it was seen that the lines whose displacements were greatest were the strongest lines of the element considered, and also those lines which occur most commonly as impurities, because of the ease with which they are rendered visible with a small amount of material; furthermore, these lines are also the ones most easily reversed in the arc. They correspond to the "long lines" of Lockyer. The lines which were least displaced, or which were in some cases displaced toward the red as compared with the corresponding solar lines, were those which were with difficulty reversed, and which required a large amount of material, or a high temperature, or both, to render them visible. These correspond to the "short lines" of Lockyer.

It was also found to be the case that, in general, the position of a line with but little material present in the arc was approximately the same as the position of the line when reversed, or in other words, produced by the absorption of the outside portions of the electric arc, when a greater amount of material was present in the arc. The density of the material where the line is produced in these two cases would be approximately the same, but there would probably be considerable difference in temperature. Generally it is only the "long lines" which can be thus compared, the "short lines" being rendered visible with more difficulty, and being much more difficult to reverse.

These two classes of lines, when visible at the same time, are produced in different portions of the arc, or rather, the bright "short lines" are produced in the central portions of the arc where the density of the material is great and the temperature high, while the reversals of the strong or "long lines" are produced at the outside of the arc where the density is much less and the temperature lower.

If both classes of lines are produced in the same part of the solar atmosphere under identical conditions, then the line in the spectrum of the arc which agrees most nearly in position with the corresponding solar line must be produced under conditions the most nearly similar. As the solar line agrees most nearly in wave-length with the line produced in the center of the arc where the temperature and density are high, it follows that we have a means of determining the pressure, or temperature, or both, of the solar atmosphere where the Fraunhofer lines are produced, if we can separate the effects of temperature and pressure.

When the metallic lines in the less refrangible portions of the spectrum were measured for the table of standards, the behavior of the lines under different conditions was noticed, and it was found that with an increase in the amount of material in the arc there was an increasing displacement of the line toward the red, unless the line became reversed, when all further progress in that direction ceased.

When Professor Michelson published his observations upon the multiplicity of the lines of certain substances, those lines were observed in the arc with a concave grating of 20,000 lines to the inch, and 21 feet 6 inches radius. My observations confirmed his as to the multiplicity of the lines in question, but led to the suspicion that the multiplicity was caused by a complicated series of reversals.[1] The shifting of all these lines with variation of the density of material in the arc was observed carefully, and found to be very great. Particular attention was paid to certain lines of cadmium which Professor Michelson had found to be of a simple character. His observations were confirmed. As the red cadmium line, although easily rendered visible with a small amount of material in the arc, was only reversed with difficulty it was specially studied; and it was found that if the micrometer wires were set upon it with very little cadmium in the arc, then as the amount was increased, the line almost bodily left the cross-hairs, always moving toward the red. As the line retained its symmetrical shape this could not be due to an unsymmetrical broadening produced by the shading of the line increasing chiefly on one side. Beside this, the change in position was altogether too great to admit of this explanation.

In his work Professor Michelson took three of the cadmium lines as standards and determined their wave-lengths with very great accuracy; but when his results are compared with the wave-lengths of the same lines in Professor Rowland's table, there is a difference of two-tenths of an Ångström unit. Professor Rowland is of the opinion that the difference is due to an error in the wave-length for the D_1 line taken as the standard of is table. Probably this is true to a considerable extent; but he difference is in the direction that it should be according to he results given above. The wave-length should be less in a acuum than in the electric arc at atmospheric pressure.

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[1] I expect to publish my results shortly.

Considering the subject carefully there seemed no reason to oubt that the wave-length of a line depended, to a certain xtent, upon the conditions under which the material producing e line was present in the electric arc, the vacuum tube, or the lar atmosphere; or in other words, the vibration period of an om depends to some extent upon its environment. An increase f the density of the material, and presumably an increase of ressure, seemed to produce a damping effect upon the vibraon period.

There was at the time no opportunity and no means at hand, of arrying out the investigation further, and I have had no oppornity of pursuing the matter further since then, though some easurements were made, and through the kindness of Dr. S. Ames, a synopsis of a paper embodying some of these sults and ideas, was read at the Astrophysical Congress, at the olumbian Exposition at Chicago, in the summer of 1893.

Being closely engaged upon other investigations, and hoping r an opportunity to secure more material, the paper was not cometed and published, though more material was gradually accumuted, with the intention of soon publishing my results. Recently, wever, Messrs. J. F. Mohler and W. J. Humphreys of this iversity have, besides observing the behavior of lines with rying density of material in the arc, considerably extended the ope of the work by observing the behavior of lines with the arc der pressures of from a quarter to about fifteen atmospheres.[1]

In the accompanying table will be found the differences in e wave-length of solar and metallic lines for several substances hich occur in the Sun. Many more lines were measured, but ose lines which were found upon investigation to be due to early coincident lines of two or more substances in the Sun, or vhich in the spectrum of either the Sun or arc were so closely associated with other lines as to affect the measurements, were rejected. The first column gives the origin of the solar line, the second column the intensity and character of the solar line; the third the intensity and character of the metallic line; the fourth the wave-length of the solar line (taken from the table being published in the ASTROPHYSICAL JOURNAL); the fifth the wave-length of the metallic line; the sixth the displacement of the metallic with respect to the solar line; and the seventh column the number of measurements upon which the wave-length of the metallic line and the displacement are based.

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[1] See page 114.

In the columns for intensity and character, *S* means *shaded*, and *R*, *reversed*. The wave-lengths of the metallic lines are the means of the different measurements. There are a number of discrepancies, as would be expected under the circumstances, because the measurements upon many of the plates were made for other purposes, and upon some of the plates the solar or metallic lines, or both, were not of an ideal character. None of the plates were made for this investigation, so that in some cases they were not well suited for this purpose. The displacement given was not determined from the difference in wave-length of the metallic and solar lines as given in the table, but from measurements of the position of the solar and metallic lines upon the same plate. In some cases the solar line was unsatisfactory for the purpose of measurement, and the differences of the wave-lengths between the metallic and solar lines taken from the table would be more accurate, but the general agreement shows that the values given are in general fairly accurate, when we take into consideration the difficulties of measurement, and that in some cases there may be other substances which help produce the solar line in addition to those known.

It will be observed that the stronger reversed lines are those whose displacement is greatest, and that there is a gradual decrease in the amount of displacement as the lines are weaker and more difficult to reverse. It will also be seen that there is considerable difference in the displacement for the lines of different elements. Generally, when there is much of the material producing the lines investigated, the reversal of a line which is produced upon the outside of the arc, where the density is slight and the temperature comparatively low, agrees approximately with the position of the same line, not reversed, when there is but little material present, and as a consequence the line is produced in the center of the arc, where, although the density (of the material producing the line) may be slight, the temperature is high. There are exceptions, however, particularly in the case of the lines of aluminium, manganese, barium, and strontium, where the lines produced under the circumstances mentioned do not coincide. In all of these cases the reversed line has the lesser wave-length. Whether the nature of other material present in the arc affects the result remains to be investigated. An increase in the quantity of the material producing the line always displaces the line toward the red; an increase in the quantity of other material does not seem to change the position of the line to the same extent, and in some cases, if not in general, changes it very little, if any. There are some indications that the position of a line depends in a measure upon what other substance is present, but it cannot be safely asserted that such is the case without further investigation.

This seems to have a bearing upon the question of the effect of temperature in changing the wave-length. If the reversed line and the fine bright line produced under the conditions considered are identical in position, then a change of temperature can have no effect in changing the wave-length; but, if the fine bright line is displaced with respect to the reversed line, the wave-length of the line, and, consequently, the vibration period of the atom must depend upon the temperature, unless the presence of other matter in the arc accounts for the displacement.

An observation bearing upon this subject is the appearance of a line when reversed more than once. In these cases each reversal is displaced toward the violet with respect to the preceding one, while the outside or last reversal is the one which most nearly coincides with the fine bright line. This is shown in a large number of cases, a good illustration of which is that of the magnesium line *b*, in the arc, a curve of the intensity of which is given in Fig. 6.

Additional evidence is given by several plates which were taken by Messrs. Mohler and Humphreys in which, upon the same plate, were one spectrum produced by using a weak electrical current, and another spectrum produced by a strong current. In some instances the quantity of material used was greatest with the weak current in order to produce lines having the same appearance in the two cases, as the stronger current would volatilize the material more rapidly, and, as a consequence, the density of the vapor would be about the same in both cases. Little, if any, displacement was observed upon these plates.

These several lines of investigation all lead to the conclusion that the wave-length is affected but little, if any, by change of temperature.

The reversals of the lines in the arc, as well as certain peculiarities in the apperance of some of the lines in the solar spectrum, when seen with the best definition, present many interesting peculiarities and some difficulties. As it is expected that this subject will receive further consideration at another time, I will only give some illustrations here.

A STUDY OF THE CHARACTERISTICS OF LINES PRODUCED BY THE ELECTRIC ARC.

Various considerations, as well as the appearance of lines in the spectra of the electric arc, show that taking the case of a line and the behavior in regard to it of different portions of the arc, we would obtain something like the following results.

The inner portion of the arc, where the temperature is high and the density greatest, would produce a broad bright line, brightest in the middle and gradually decreasing in intensity at the sides. There would be little if any trace of absorption, and, if any, it would be a broad line but of a very faint character. The outer envelopes of the arc, where the temperature is lower and the density least, would produce a comparatively faint and very narrow emission line, and an intense but very narrow absorption line. The intermediate envelopes would give results intermediate between these extremes. In Fig. 1 the upper curves give a representation of the spectral appearance of an emission line as produced by envelopes at different distances from the center of the arc. The lower curves represent the corresponding absorption line. In Fig. 2 the upper curve represents the emission line produced by the combined effects of all of the envelopes and the lower curve the corresponding absorption line,

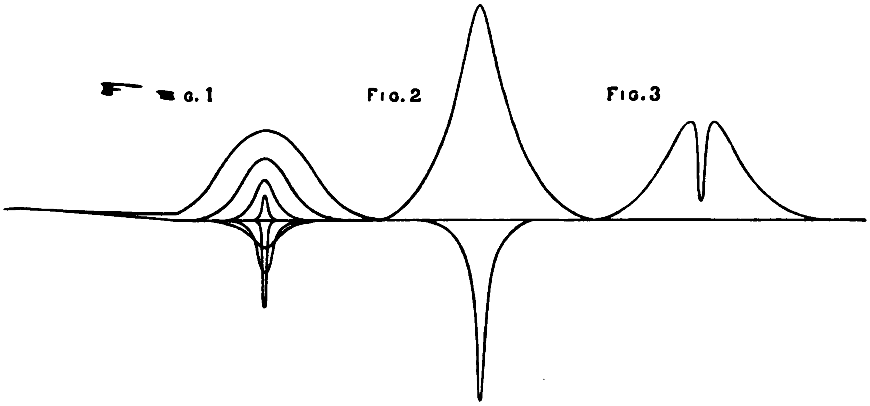


FIG. 1 FIG. 2 FIG. 3

while Fig. 3 represents the reversed line which is a combination of these two effects. Both figures represent the typical cases generally seen in metallic spectra. From these considerations we may say that the width of a line depends upon the density of the material which produces it, and the pressure to which it is subjected. Whether the width depends directly or indirectly upon the temperature cannot be stated with certainty, though it is probably affected in both ways.

The intensity or brightness of a line of emission will depend upon the temperature of the material producing it, and the number of vibrating atoms from which the radiation is received.

The intensity or darkness of an absorption line will depend inversely upon the temperature, and directly upon the number of atoms whose sympathetic vibrations produce the absorption. (There are, however, limits to both effects.)

The character of a line produced in the electric arc will depend upon the distribution and density of matter in the envelopes from the center to the outside, and the relation of the radiating to the absorbing capacity of the matter composing these envelopes, and this will depend largely upon the distribution of temperature. The intensity curve of the line in Fig. 3 represents a typical case, but there are other cases which are widely different.

If there is a gradual change in the factors mentioned, from the center to the outside of the arc, we will have produced lines somewhat similar to those represented by Figs. 2 and 3; but, if there is not a gradual change in these factors, upon which the character of the line depends, and if the material of the arc is in a series of concentric layers, of maximum and minimum density, or if the change in the relation of the radiating to the absorbing capacity of the matter in the arc is not gradual from the center to the outside, but is variable in such a way as to give maxima and minima of intensity of radiation and absorption, we might have a series of multiple reversals such as is represented by the magnesium line in Fig. 6, and which is sometimes even more strikingly shown by the magnesium line at λ 2852.239 (one photograph shows four reversals of this line), and also readily shown by the sodium lines D_1 and D_2 in the arc.

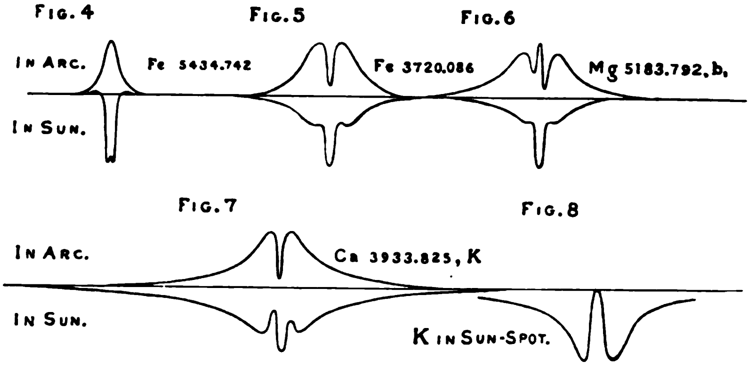
A better explanation, differing somewhat from the above, is perhaps to consider the effect as produced by a large amount of material in the arc while the temperature is comparatively high, even near the outside of the arc. The central portions would give a very broad emission line, while the intensity of the absorption up to a certain distance from the center might be such as to prevent the transmission of any radiation whose period differed within certain limits from the fundamental or principal period. The absorption band produced would be, however, narrower than the emission line produced by the central portions of the arc. The radiation then produced by the matter from this layer to one somewhat further away, would give an emission line narrower than the absorption band given by the other layers nearer the central portions of the arc, and the absorption of the layers further outside would produce a still narrower absorption line. The total or combined effect would be that of a multiple reversed line.

Taking into consideration the shift or change of wave-length with increasing density of material, or increasing pressure, the matter is somewhat further complicated. If the radiation from the denser portions of the arc constitute the principal source of the emission line, and particularly if the radiation corresponding to the middle of the line increases in intensity as the breadth of the line increases, the appearance of the emission line will remain symmetrical or nearly so, though where there is absorption on the outside, the reversal will be displaced toward the violet with respect to the center of the line. These are the ordinary types of lines.

However, if the intensity of radiation for the sides of the line increases more rapidly than the middle as the breadth of the line increases, and if the intensity of radiation corresponding to the middle portions of the line, falls off slowly from the center to the outside of the arc, an unsymmetrical emission line will be the result, or the line may be said to be unsymmetrically broadened. The question of temperature and temperature distribution in the arc probably largely controls this matter of the unsymmetrical broadening of lines. This is strongly indicated by some results that Messrs. Humphreys and Mohler obtained in their work; however, the whole question of the effect of temperature on the arc is in an unsatisfactory state.

CERTAIN PECULIARITIES IN THE APPEARANCE OF LINES IN THE SOLAR SPECTRUM, AND THEIR INTERPRETATION.

When the lines in the solar spectrum are examined carefully, in the light of the preceding considerations, some interesting facts are brought out. When some of the very best negatives of the solar spectrum are carefully examined, it is found that some of the sharp-edged, clean-cut, and unshaded lines of iron, chromium, manganese, titanium, etc., have a faint, dark shading just outside the edge of the lines. It is very faint and difficult to observe (only slightly darker than the general background of the solar spectrum), but is not due to contrast, as it is not always present. It is a difficult observation to make, but was observed for some time before the explanation forced itself upon me. The correct explanation undoubtedly is that this faint, dark shading (dark in the negative) is the remains of an emission line, either produced at the photosphere or lower down in the solar atmosphere than the absorption line. A good example is that of the iron line at λ 5434.742, an illustration of which is given in Fig. 4. (The lower curve is the solar line and the upper curve the metallic line.) The reason more good cases are not found, is that but few solar lines of this character are sufficiently isolated from fine lines, which mask the effect. Almost all lines of this character, however, show traces of this underlying emission line.



This emission line is rather broader than the absorption line (perhaps nearly two or three times as broad), and, consequently, is produced lower down in the solar atmosphere, where the pressure is much greater than in the strata giving us the absorption line. Another noticeable fact is the clean-cut, almost unshaded edges of these lines, showing that there is a considerable amount of gas (or a gas of intense absorbing power for radiations of this period), producing the absorption, which varies comparatively little in pressure. In most of these lines whose width is sufficient to show the effect, there is a faint reversal showing matter at a somewhat lower pressure (consequently somewhat higher in the solar atmosphere), giving a faint emission line.

When the shaded lines are examined we find a different state of affairs. A good example is the iron line at λ 3720.086 and the magnesium line at λ 5183.792 (b_1). They are represented in Figs. 5 and 6.

Any trace of the primary emission line would be masked by the shading and would be too faint to be observed, but the most characteristic feature of these lines is the shading, which increases in intensity from the edges toward the central line. This is probably the first absorption line produced by the solar atmosphere. The gas producing this shading appears to have nothing like the same intensity of absorption for radiations of this wavelength as was found in the case of the other iron line, but is under a much greater range of pressure. When we consider the width of this shading and the width of the other line, and compare the result with the two corresponding iron lines in the spectrum of the arc, we are led to conclude that the gas producing the broader portion of this shading is situated at the same level in the solar atmosphere as the gas producing the other absorption line, but that the gas producing the whole of the shading extends through a much greater range of pressure and extends to a considerably higher altitude.

Examining the figures again we notice that there are traces of an emission line which must be produced at a higher altitude, as we see only the faint edges of this line (most of it being obliterated by the absorption of the central line). This emission line is not very noticeable. Inside this we find an intense, rather clean-cut, absorption line of nearly the same width as the other iron line, but slightly narrower, and not quite as sharp-edged as the other. This is the second and last absorption of this line. When we take into consideration the relative intensity of the two corresponding metallic lines, we find that this last absorption must be produced much higher up in the solar atmosphere than the other line, where the pressure is very much less.

The appearance noticed is shown to a greater or less degree by all distinctly shaded lines in the solar spectrum. When the calcium lines H and K (Fig. 7) are examined the same state of affairs is shown, but to a much more remarkable degree. The primary emission line is of course invisible, but the extreme breadth of the shading, of both H and K, shows that the first absorption must persist through an extreme range of pressure, or that the amount of calcium gas varies enormously in the solar atmosphere where this absorption is produced. The second emission line of calcium is rather prominent in both H and K, but much more so in K, it sometimes being scarcely noticeable in the case of H.

The central absorption line is rather strong in both cases, but not so strong as in the shaded lines of iron, magnesium, and aluminium. This may be in part due to the background against which it is seen, but only in part, for the line has something of a diffuse appearance, similar to the lines of hydrogen, and unlike those of iron, etc. This central line is not much wider than the other lines considered, showing it to be produced by the absorption of calcium gas at a still greater elevation in the solar atmosphere.

An appearance that attracts attention is the unsymmetrical character of the central absorption line with respect to the emission line. This is more easily observed in the case of K than H, partly because the emission line is stronger, and partly, as we may say, it is less littered up with lines belonging to other elements, the neighborhood of the central line of K being almost free from other lines.

When different plates are examined, it is found that this dissymmetry varies upon different plates, to a considerable extent. Upon some plates the central absorption line is almost symmetrical with respect to the emission line, while upon other plates its unsymmetrical character is very marked, the central line being displaced considerably toward the red, and the part of the emission line on the violet side of the central line being much the strongest.

The central absorption line also varies somewhat in width upon different plates, and the position of the maximum intensity for this central absorption line also varies from the middle of the line in some cases, to a considerable distance on either side in other cases. The emission line also varies somewhat in intensity and breadth.

A number of these plates have been measured and as a result it is found that the central absorption line varies in position to the extent of 0.025 of an Ångström unit, between the plates upon which the central line is symmetrically placed and the plates upon which it is most unsymmetrical. The displacement so far as has been observed, is always toward the red. In no case examined so far has the central line been perfectly symmetrical with respect to the emission line, or displaced toward the violet, and in no case has its wave-length been less, but always slightly greater than the corresponding metallic line. H gives the same results as K, but is more difficult to measure with accuracy.

An attempt was made to measure the position of the emission line in these cases. The measurements were too difficult to make to give any certain results, but there were some indications that the emission line might be slightly displaced toward the violet in the cases of dissymmetry. There are some indications, however, that these displacements in opposite directions of the absorption and emission lines are not compensatory, although probably connected with each other. The obvious explanation is that in the cases of dissymmetry we have examples of motion in the line of sight, the displacement of the central absorption line being due to falling matter, the extreme difference in velocity, shown by different plates, being about seventy-five miles per minute.

This downrush of matter is probably accompanied by an uprush from below corresponding to the emission line. Its velocity cannot be satisfactorily determined because of the character of the line, and the interference of the absorption line. A velocity considerably less than that of the downrush is however indicated, although this may be accounted for by other considerations. The position of the central absorption line should be nearly the same as that of the corresponding fine reversal in the arc, providing there be no motion of either in the line of sight, as the matter producing both are probably at a comparatively low pressure and density. The emission line should, however, be displaced somewhat toward the red, as it is produced under greater pressure. Evidently this displacement due to pressure is overcome by the velocity of the uprush, as the emission line has nearly the same position as the metallic reversal. More than this I cannot say, as measurements are too difficult to be very accurate.

It is quite likely that the somewhat diffuse character of the central absorption line, and its lack of intensity when compared with the corresponding lines of iron, magnesium, and aluminium, may be the result of this motion in the line of sight, and this explanation is strengthened by the change in the position of maximum intensity noticed. Thus as a result of more or less variation in velocity, the line might be spread out considerably, whereas from the probable elevation and low pressure existing in that portion of the solar atmosphere where this central line is formed, we would expect to find a very narrow line, as the metallic reversals of H and K are generally narrow lines. (The curve in Fig. 7 represents the usual appearance of H and K in the spectrum of the arc, though the curve for b_1 in Fig. 6, — not the usual appearance of b_1 in the arc, but an exceptional case, — corresponds more nearly to the appearance of H and K in the solar spectrum.)

There are no dates upon the plates measured, which renders the matter uncertain, but there are indications that the plates showing the displacement were not taken at the same time as the others, possibly at a different part of the Sun-spot period. More or less dissymmetry seems to be the usual state of affairs, and symmetry the exception. This explains the extreme displacement of the metallic with respect to the solar lines, in the cases of H and K. In Fig. 8 is given the appearance of H and K as observed in the spectrum of Sun-spots, with a large plane grating. The absorption of light of this wave-length, by the two large lenses of the spectroscope, was so great that the finer details were difficult to observe, but the bright reversals of H and K (emission-lines in this case) in the neighborhood of a spot were clearly visible, as well as the intense absorption in the shading near the reversal (the shading further away not seeming to be greatly affected). The absorption toward the red from the reversal was considerably darker and broader than toward the violet, thus giving evidence of considerable relative velocity between the emission line and the broad absorption line or shad ing. The narrow central absorption line was not observed.

The shaded lines of other elements have been examined, and their positions measured upon the same plates used in the determinations for H and K, with the following results. The strongest lines of iron show a displacement upon one set ot plates, with respect to another set, similar to that observed in the case of H and K, but to a much less extent. The extreme difference in velocity shown by the strongest iron lines is about twenty-five miles per minute, and a smaller velocity is shown by the lines of less strength. It is imperceptible in iron lines without considerable shading, and in the case of the weaker lines of iron there is no evidence whatever of any displacement or irregularity.

The aluminium lines show a difference in velocity of about fifteen miles per minute, while the shaded line of silicon at λ 3905.660, and the magnesium lines show no evidence of a change in velocity. Likewise there is no evidence of any variation in the carbon bands nor the weaker lines of any of the elements, one case being the faint calcium line at λ 3949.056, which shows no evidence of variation. As these measurements were confined to those plates containing H and K, the calcium line at 4226.904 (*g*) was not observed. Another interesting fact in this connection is the variation in the relative positions of the absorption and emission lines of the strongest of the iron lines Upon the plates that show H and K symmetrical, the emissio line of iron shows quite distinctly upon the side of the absorptio line toward the red (this is also shown distinctly in the case o the calcium line *g*, and is probably the effect of the greater pressure of those portions of the solar atmosphere where the emissio line is produced). No trace of it can be seen upon the viole side. Upon the other plates the absorption and emission line are symmetrically placed with regard to each other, or, in som cases, the emission line is most distinct upon the violet side Some of these features are indicated in other shaded lines, bu not at all distinctly.

Another observation of interest is the variable intensity of line at λ 3719.801, which is situated in the shading of the stron iron line at λ 3720.082. It can be seen upon Professor Rowland' map of this region, and is quite distinct upon some plates, whil not visible upon other plates showing lines closer to the iro line, and which are much weaker than the variable line upon th plates first mentioned. Other plates show this line between thes extremes. A feature of the shaded lines to which attentio should be called is the surprising weakness of this shading whe we consider the great depth of the solar atmosphere when compared with the depth of what may be called the atmospher surrounding the electric arc. The pressure indicated by th breadth of the shading must be very great at the lower depth of the solar atmosphere, but the comparative weakness of th shading would indicate comparatively little of the material producing the shading, or a feeble absorbing power. This weaknes is rendered conspicuous when contrasted with the marke increase in the darkness of shading produced by a Sun-spot. I may be that vibrations easily produced at much lower temperatures are absorbed feebly by gases at much higher temperatures The effect may also be accounted for by the eruptive nature o the photosphere, thus mingling the effects of an emission wit an absorption line in the spectroscope, which may be unable t distinguish between the two with a small image of the Sun. I the feeble absorption at high temperatures of radiations easily produced at lower temperatures, has anything to do with the appearance noted we may possibly account for the peculiar behavior of the calcium line *g*, which in the arc has the same appearance as H and K, but, unlike these lines in the Sun (which indicate the presence of enormous quantities of calcium in the solar atmosphere), the appearance of *g* would indicate the presence of comparatively little of the material producing this line.

Summarizing results, we may say that in some cases we can, in all probability, actually see through the cooler absorbing atmosphere of the Sun, and observe the original emission lines of the photosphere, or the gases immediately above it. Also, that while all the metallic lines in the solar spectrum are actually produced in those portions of the solar atmosphere close to the Sun's surface, the solar line, as we generally recognize it, may in some cases be produced at a considerably higher altitude. (In the case of H and K the central absorption line may possibly be produced by the corona.)

This effectually disposes of the necessity of any dissociation hypothesis to account for most solar phenomena.

Two adjacent lines of iron, for instance, may show the effects of a violent motion of iron vapor in opposite directions, in the neighborhood of spots, or one line (the smaller one-corresponding to one of Lockyers "short lines") may show a broadening and increase of intensity in the spectrum of a Sun-spot, while the other line (the larger one-corresponding to one of Lockyer's "long lines") is unaffected. But this does not prove that iron vapor is dissociated in the Sun. It merely shows that the apparently similar portions of the two lines in the solar spectrum are produced at different elevations in the solar atmosphere. The stronger iron line will be affected in a Sun-spot as much as the other one, but it is the portion of the line produced at the same level as the other line and may be masked completely or very largely, by the emission line produced at a higher level, while the second absoption line in the solar spectrum may be entirely unaffected, being produced at a still higher altitude.

This also explains why some of the lines (the short lines generally) of an element may be most prominent in Sun-spot spectra, while others (generally the long lines) are those most frequently seen in prominences or in the chromosphere.

Another fact bearing upon this question is that the shading of K (and to a less extent of H) is partially broken up into a series of faint nebulous lines, symmetrically situated about the central line. Some of these lines (which are absorption lines) are partially visible upon nearly all good plates of this region showing sufficiently good detail, but they are plainly visible upon only one plate (all of the lines upon this plate with the exception of the symmetrical series of H and K are visible upon the other plates and identical in their positions, relative intensities, etc.). The reason for this may be partially due to the comparatively weak character of the emission line upon this plate, thus unmasking these lines which are formed at a lower elevation, or it may be due to special conditions prevailing at the time the plate was taken. The slit of the spectroscope may have been over a group of Sun-spots, though the fact that the absorption shading of K (with the exception of these extra lines) is comparatively weak upon this plate, renders this explanation doubtful, though possibly the most probable one. That it is a series of calcium lines and connected with the shading of the K line is rendered certain by the symmetrical character of the series.

The strong shaded lines of iron also show this same kind of symmetrical series (though there are some differences). The best results are given by the iron line at λ 3720.086, which is probably the strongest line in the spectrum of iron and also the one freest from the contaminating influence of other lines. These faint series are visible upon all good plates in the third spectrum of a 20,000 grating of 21 feet 6 inches focal length, but are not visible with much distinctness in the second spectrum, the dispersion not being quite sufficient.

The shadings of other lines show some indications of breaking up into series, but will require greater dispersion to render the

DISPLACEMENT OF LINES.

	Intensity		Wave-length		Displacement	Number of Observations
	Sun	Arc	Sun	Arc		
Fe	3	3	3424.439	.444	+ 6	1
"	15 S	10 R	40.770	.761	− 9	1
"	12 S	10 R	41.163	.145	− 6	1
"	4	3	45.302	.308	+ 6	1
"	10 S	8 R	90.740	.722	− 7	1
"	6	5	97.991	.990	− 4	1
"	5	4	3536.706	.704	− 4	1
"	7	6	41.233	.240	+ 7	1
"	6	5	55.077	.072	− 6	1
"	40 S	30 R	81.352	.338	− 7	1
"	4	3	3617.935	.934	+ 10	1
"	18 S	15 R	18.931	.912	− 8	3
"	3	3	22.148	.155	+ 4	1
"	15 S	12 R	47.989	.983	− 13	2
"	4	3	49.655	.656	+ 3	2
"	10 S	8 R	87.610	.597	− 8	1
"	10 S	8 R	3705.710	.704	− 4	1
"	50 S	50 R	20.082	.075	− 11	2
"	4	4	24.526	.519	− 4	1
"	1	1	31.093	.084	− 6	1
"	40 S	40 R	35.014	.005	− 7	3
"	30 S	30 R	37.281	.270	− 12	3
"	4	3	38.454	.448	− 13	1
"	18 S	20 R	45.717	.691	− 9	1
"	15 S	18 R	46.058	.044	− 9	1
"	15 S	15 R	48.408	.406	+ 3	2
"	20 S	20 R	49.631	.628	− 6	3
"	2	2	57.081	.086	+ 2	1
"	18 S	18 R	58.375	.376	− 3	3
"	3	3	60.196	.198	− 1	1
"	3	2	60.679	.681	+ 1	1
"	12	12 R	63.945	.932	− 6	2
"	10	10 R	67.341	.336	− 7	2
"	2	2	74.971	.974	+ 2	1
"	8	8 R	88.046	.023	− 15	2
"	4	4	94.485	.481	− 6	1
"	10	8 R	95.147	.144	− 1	1
"	30 S	30 R	3815.987	.988	− 5	2
Fe, C	35 S	35 R	20.586	.568	− 10	5
Fe	10	10 R	24.591	.584	− 8	1
"	30 S	30 R	26.027	.025	− 7	5
"	15 S	15 R	27.980	.969	− 7	2
"	8	8 R	56.524	.515	− 6	2
Fe, C	30 S	25 R	60.055	.052	− 4	4

R means once reversed.
R^1 means doubly reversed.
N means nebulous.
S means shaded.

	Intensity		Wave-length		Displacement	Number of Observations
	Sun	Arc	Sun	Arc		
Fe	15 S	15 R	86.434	.415	− 13	18
"	8	8 R	3903.410	.398	− 9	1
"	10	10 R	28.075	.059	− 9	1
"	10	10 R	30.450	.438	− 7	1
"	4	4	37.479	.467	− 5	1
"	4	5	4022.018	.022	− 3	1
"	25 S	25 R	45.975	.964	− 12	7
"	5	5	62.599	.597	± 0	1
"	18 S	18 R	63.759	.751	− 7	7
"	3	4	67.429	.435	± 0	2
"	12 S	12 R	71.908	.898	− 9	7
Zr–Fe	4	4	4199.267	.263	− 3	1
Fe	6	8	4202.198	.194	− 6	1
"	3	3	22.382	.396	+ 14	1
"	6	8 R	71.934	.917	− 16	5
"	6	8 R	4308.081	.067	− 10	4
"	8	8 R	25.939	.921	− 12	4
"	2	2	52.908	.900	− 7	1
"	4	3	69.941	.937	− 4	1
"	4	4	76.107	.097	− 10	1
"	12 S	12 R	83.720	.705	− 15	7
"	10 S	10 R	4404.927	.911	− 16	6
"	7	8 R	15.293	.286	− 6	1
"	4	4	47.892	.886	− 6	1
"	4	4	94.738	.749	+ 11	1
Ni	12	18 R	3446.415	.398	− 14	1
"	3	4 R	67.647	.648	− 4	1
"	1	3	76.408	.414	+ 6	1
"	1	4	80.323	.311	− 8	1
"	0	1	88.444	.436	− 8	1
"	10	15 R	93.121	.087	− 14	1
"	1	1	96.498	.486	− 5	1
"	3	2	3507.837	.831	− 6	1
"	8	8 R	10.461	.468	− 3	1
"	10	18 R	15.201	.179	− 20	1
"	1	1	23.206	.209	− 6	1
"	15 S	20 R	24.671	.658	− 12	1
"	1	1	29.760	.760	− 5	1
"	5	5 R	48.328	.320	− 8	1
"	3	2	51.671	.668	− 5	1
"	1	1	60.060	.068	+ 6	1
"	0	0	77.383	.377	− 5	1
"	2	3	3602.430	.422	− 7	1
"	10	18 R	19.546	.520	− 25	1
"	5	6 R	3783.674	.664	− 10	1
Co	5	7 R	3395.530	.523	− 7	2
"	7	10 R	3405.263	.257	− 6	3
"	4	8 R	3998.053	.053	− 5	1

	Intensity		Wave-length		Displacement	Number of Observations
	Sun	Arc	Sun	Arc		
Co	1	3	4092.547	.546	− 9	1
"	4	8 R	4110.691	.690	− 2	1
"	4	8 R	18.934	.918	− 8	1
"	5	10 R	21.477	.475	− 5	1
Cr	7	30 R	4254.505	.490	− 11	2
"	d? 5	25 R	74.958	.958	− 5	2
"	4	20 R	89.885	.877	− 10	2
"	2	6 R	4337.725	.718	− 6	2
"	2	6 R	39.617	.608	− 6	2
"	1	3	39.882	.874	− 7	2
"	1	2	51.216	.214	− 4	2
Mn	9	30 R	4030.918	.900	− 14	11
Fe?-Mn	8	25 R	33.224	.213	− 12	11
Mn-Fe?	d? 7	20 R	34.644	.631	− 9	11
{ Co	5		35.752			
{ Mn	6	8 R	35.883	.881	± 0	3
Mn-Ti	d? 1	3	65.239	.220	− 20	1
Mn	2	5	70.431	.410	− 19	2
Mn,-	3	6	83.095	.072	− 25	2
Cu	9	40 R	3247.698	.672	− 22	2
"	d? 6	30 R	74.098	.093	− 9	2
Mg	15 S	25 R	3832.450	.440	− 9	1
"	20 S	35 R	38.435	.427	− 8	1
Al	15 S	40 R	3944.160	.151	− 5	26
"	20 S	50 R	61.674	.665	− 8	26
K	0	25 R	4044.294	.599	+ 2	3
"	00 Nd?	15 R	47.338	.571	+ 16	3
Si	10 S	10 R	3905.660	.661	− 6	15
C	d { 0	{ 3	3876.556			
	{ 0	{ 3	76.622	.580	− 8	11
Sr	8 S	40 R	4077.891	.866	− 16	6
Fe	{ 2		4215.581			
Sr	{ 4	45 R	15.703	.682	− 15	5
Sr	2	50 R	4607.510	.505	− 7	8
Ba	d? 7	45 R	4554.211	.204	− 10	2
"	d { 3		4934.214			
	{ 4	50 R	.277	.252	− 20	1

	Intensity		Wave-length		Displacement	Number of Observations
	Sun	Arc	Sun	Arc		
(K) Ca	100 S, R^1	100 R	3933.825	.794	− 23	26
Ca	1	3 N	3949.039	.056	+ 2	5
(H) Ca	80 S, R^1	90 R	68.625	.603	− 24	26
Fe	1		73.796			
Ca	3	6 N	.864	.864	± 0	5
(*g*) Ca	12 S	70 R	4226.904	.885	− 10	7
Ca	4	8 R	83.169	.162	− 8	6
"	3	8 R	89.525	.514	− 5	7
Ca, Mn?	3	8 R	99.149	.140	− 13	7
Ni ?, Ca	5	15 R	4302.692	.681	− 12	7
Ca	3	8 R	07.907	.894	− 10	6
Ti-Ca	4	10 R	18.817	.808	− 10	7
Ca,-	5	8 R	4425.608	.599	− 9	12
-, Ca	5	12 R	35.129	.123	− 6	12
Ca	4	8 R	35.851	.846	− 6	11
Zr?-Mn?, Ca	5	15 R	54.953	.941	− 10	10
Mn?-Ca	4	7 R	56.064	.056	− 4	3
Ca	3	2	5189.018	.010	− 8	1
"	0	0	5260.561	.549	− 4	1
Ca-Cr	3	2	61.876	.864	− 10	1
(E^1) Ca	4	4 R	70.438	.430	− 9	2
Fe	4		.558			
Ca	4	5 R	5582.198	.203	+ 7	4
"	6	12 R	88.985	.973	− 11	4
"	4	5 R	90.343	.347	+ 5	4
"	5	10 R	94.691	.683	− 6	4
"	5	8 R	98.711	.709	− 5	4
"	4	6 R	5601.505	.509	+ 4	4

series certainly visible. These series must be produced in t lower portions of the solar atmosphere, not far from t photosphere, where the temperature must be very high, an consequently it is evident that, whatever else may be said abo it, iron and calcium atoms are not dissociated and broken up int simpler atoms, at the extreme temperature of the lower portions the solar atmosphere.

The observations which I have considered have an imp tant bearing upon many solar problems. By taking phc graphs either of opposite edges of the Sun, or still better manner similar to that of Professor Keeler in his work upon rotation period of Saturn's system, it will be possible to d mine the velocity of rotation for different heights in the solar atmosphere, by making a proper selection of lines for use, and taking the plates upon a large enough scale.

Another effect of this investigation may be to make the lines of the solar spectrum step down from the commanding position which they have occupied, as the standards of reference, for all work connected with the determination of the wave-length of any sources of light where extreme accuracy is required. In the case of the strong shaded lines we have proof that their positions are not the same upon different plates because of motion in the line of sight, and the amount of this motion evidently depends upon how high an elevation in the solar atmosphere the material producing an absorption line reaches. We also see that the wave-length of a solar line depends upon the depth in the solar atmosphere at which it is produced, and consequently upon the density and pressure at that level.

For nearly all practical purposes, however, the lines of the solar spectrum will answer perfectly well for standards of reference, if we exclude those lines which are produced at a considerable elevation. All other lines will probably retain a fixed position relatively to each other.

The lines of the electric arc will answer poorly where extreme accuracy in any future work is required, and it may be the duty of the vacuum tube to furnish our future exact standards, but it remains to be seen yet whether they will remain steadfast and true, or not. Professor Michelson's work would indicate that the lines thus produced are very constant in position.

In conclusion I should say that I am indebted for most of the material for this investigation of solar phenomena, to the series of beautiful negatives of the solar spectrum, which Professor Rowland made for his map of the normal solar spectrum. The grain of these plates is exceedingly fine and the definition almost perfect.

JOHNS HOPKINS UNIVERSITY,
Baltimore, Md., December 20, 1895.

EFFECT OF PRESSURE ON THE WAVE-LENGTHS OF LINES IN THE ARC-SPECTRA OF CERTAIN ELEMENTS.

By W. J. HUMPHREYS and J. F. MOHLER.

OBJECT AND METHOD.

THE purpose of the investigation described in this paper was to examine minutely the effects of pressure on the arc-spectra of the elements, and especially to note the effect, if any, on the wave-length. This idea was suggested by the fact that in the course of careful measurements of the arc and solar spectra made in this laboratory by Mr. L. E. Jewell, he detected certain discrepancies which showed a difference in the wave-lengths of the same line in the two spectra, and also that this difference varied with different elements.

A further reason for taking up this work was the fact that the wave-lengths of the red, green, and blue lines of the spark spectrum of cadmium vapor at low pressure as determined by Professor Michelson[1] for the purpose of accurately comparing them with the standard meter, are less than those of the same lines of the arc-spectrum at atmospheric pressure as determined by Professor Rowland;[2] the difference being .208 of an Ångström unit for the red, .173 for the green and .186 for the blue line. That their measurements, made in totally dissimilar ways, should differ by one part in thirty thousand is not surprising, especially since Professor Rowland's measurements are relative rather than absolute; but that there should be one difference for the red, and another for the green line, and that these should not be equal to each other by an amount too great to be considered an error of observation on the part of either or both of these skillful experimenters is remarkable, and it was hoped that the present investigation might explain, in some measure, this want of agreement.

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[1] *Détermination expérimentale de la valeur du mètre en longueurs d'ondes lumineuses.*

[2] ROWLAND, *A. and A.*, 12, 1893.

On examining spectroscopic literature it was found that many observers had noticed the fact that increase of material broadened the lines. Some of the lines spread out symmetrically, others unsymmetrically, the increase in width being chiefly on the less refrangible side.[1] Similar results have been noticed when the source of light was under pressure. In both cases the width of a line probably depends in part at least upon the vapor pressure of the element that produces it, since, according to Schuster,[2] when gases are mixed in different proportions the lines of any one become sharper when it is present in smaller quantity, though the total pressure may remain the same.

Various theories have been proposed to explain the phenomenon of broadening of spectral lines, but nowhere have we found stated as a result of theoretical considerations or experiment that the wave-frequency itself may change and thus lead to a shift of the line as a whole. However, in speaking of absorption spectra, Kundt[3] says: "The position of the absorption band of a substance depends very essentially on the dispersion of the medium in which it is dissolved or incorporated. One often observes that in strongly dispersive media the absorption bands of a substance are displaced toward the red." It would appear from this that one might suspect the possibility of a similar phenomenon in the case of emission spectra.

In examining the effects of pressure on arc-spectra we used a twenty-one and a half foot concave Rowland grating of 20000 lines to the inch, mounted as described by Dr. Ames in the *Johns Hopkins Circular* of May, 1889. The arc was produced by a direct 110-volt current of any amperage desired, which, judging from the fuses blown, occasionally amounted to fifty or more. The pressures were always obtained by pumping air into a piece of apparatus designed by Professor Rowland several years ago and used by Messrs. Duncan, Rowland and Todd[4] in their examination of the electric arc under pressure. It consists, as shown by Plate XI., of a cast-iron cylindrical vessel A, having at each end stuffing boxes B, B' through which pass insulated rods D, D' carrying carbons C, C'. The upper rod is regulated by a rack and pinion P, and the lower one by two screws S, S. The cylinder is prevented from becoming too hot by the water jacket K. A plane piece of quartz Q allows light from the arc to reach the spectroscope, and the window W enables one to know when the carbons are in proper position before turning on the current. The pressures were given by a gauge which could be read as often as desired, though it never changed appreciably after the current was on a few seconds.

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[1] KAYSER and RUNGE, *Abh. d. K. Akad. d. W. Berlin*, 1890–1.

[2] *Ency. Brit.* "Spectroscopy."

[3] KUNDT, Jubelband, *Pogg. Ann.* p. 620.

[4] *Electrical World*, **22**, 1893.

Nearly all the work was done in the second spectrum, the dispersion being a little more than one millimeter per Ångström unit.[1] Some observations were taken directly with a micrometer eyepiece, but most of the results were obtained from photographs which were measured on a dividing engine especially constructed for this sort of work, and used in determining Rowland's[2] table of standard wave-lengths.

The camera of the spectroscope, which takes a nineteen by one and a quarter-inch plate, is arranged for making two successive exposures, one on a narrow strip along the middle of the entire plate and the other on the remaining portions. In front of the camera were arranged shutters that enabled us to follow our usual method of photographing, which was to expose about an inch of the middle strip of the plate to the Sun, then the remainder of strip to the arc under pressure, then the corresponding outer portions to the arc at atmospheric pressure, and finally the remaining parts to the Sun. If plate or instrument had moved during the exposure the solar lines would thus have shown it. Besides, it was noticed that the lines of the carbon bands were never appreciably shifted and so these, some of which were found on nearly every plate, as well as the solar lines, enabled us to detect any disturbance of the apparatus during exposure. Unless stated to the contrary, a hole bored along the axis of the positive pole was filled with the material whose spectrum was to be examined.

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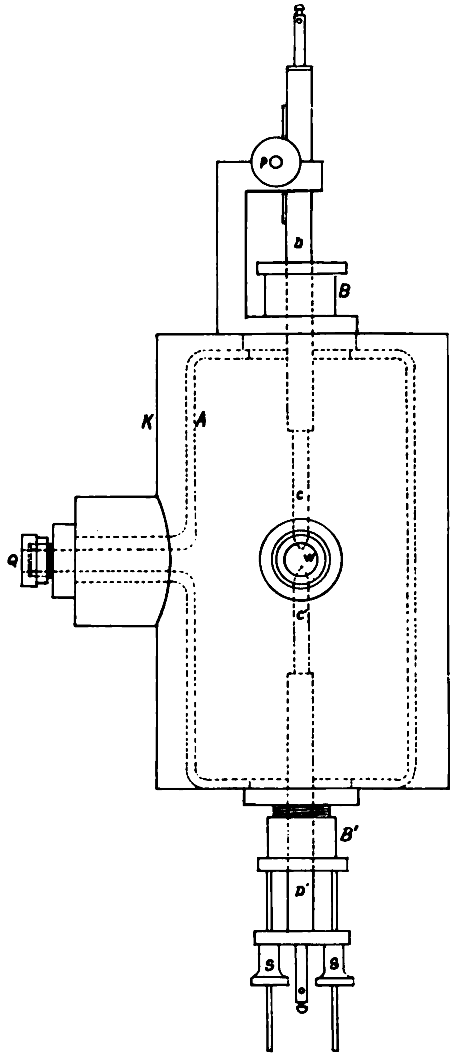
[1] In all this work Rowland's scale is used.

[2] *A. and A.*, 12, 1893.

PLATE XI.



EXPERIMENTAL RESULTS.

Our first work was done with cadmium at atmospheric pressure. On varying the amount of material in the arc the width of the lines varied accordingly, and a large amount brought out clearly the reversals of the blue and green lines. The broadening was slightly unsymmetrical, being more towards the less refrangible portion of the spectrum, while the positions of the reversals coincided with those of the fine lines given by a small amount of material. Variation of strength of current did not appreciably affect the positions of the reversals of the lines of any substance examined, though the width of numerous lines increased, that of many of them unsymmetrically with increase of current. In the case of the aluminum lines at λ 3944 and λ 3961 the red side of the reversal was much stronger than the violet side. However, when pressure was applied to the arc containing cadmium, a decided shift in the positions of the lines was at once noticed. It was not simply unsymmetrical broadening, for it was possible to obtain fine sharp lines with and without pressure; nor was it a case of one line disappearing and another appearing in a slightly different position since it was often easy, while the pressure was being let off, to observe a line gradually change its position without alteration in width or other appearance. Such alterations, however, usually occurred unless special precautions were taken.

If, as is generally believed, the temperature of the arc is that of volatilizing carbon, it would be natural to suppose that it would rise with increasing pressure; but recent experiments by Wilson,[1] on the temperature of the arc under pressure, seem to show that it is lower at high pressures. In either case the shift might be due to change in temperature rather than pressure, and to test this point we used a long arc, perpendicular to the slit of the spectroscope; and with a heavy current exposed one part of a plate to the arc close to the positive pole and the other to the arc near the negative pole, as Wilson and Gray's[2] work indicates that the temperature of the negative pole is much lower than that of the positive. We could detect no change in the position of the lines, but this of course does not settle the question as the temperature of the electric arc and how it varies from point to point is not known. Our work would indicate that the effect was that of pressure rather than temperature.

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[1] *Proc. R. Soc.* May 30, 1895.

[2] *Proc. R. Soc.* November 24, 1894.

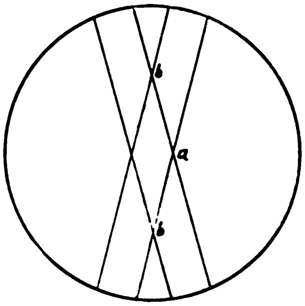

FIG. 1.

Over one hundred negatives were obtained; and the shifts of some lines—those whose positions were well defined—of twenty-three elements were measured in the following way: In the microscope of the dividing engine double cross-hairs were arranged in the manner shown in the figure, and the negative moved along by the screw until the cross *a* was on a given line of the middle strip when a reading was taken. The plate was then moved forward again by the micrometer screw until the crosses *bb* were on the same line, as photographed at different pressure on the outer portions of the plate, when another reading was taken, and so on for other lines. The plate was then reversed and the same process repeated. Let s be the shift of any line and l the difference in readings that would be given by the crosses *a* and *bb* when there is no shift, and let the direct reading of the crosses *bb* be λ, and the reversed d, then the direct reading of *a* will be $\lambda - l \pm s$ and the reversed $d - l \mp s$. Evidently $\lambda + d$ is a constant from which if the reversed readings be subtracted remainders will be obtained equal respectively to λ and $\lambda + l \pm s$. Consequently the average of the two readings given by the crosses bb is λ and that of those given by the cross a, $\lambda \pm s$, their difference being the shift $\pm s$. By this method the accuracy of our measurements was about three thousandths of an Ångström unit.

The negatives showed that the general effect of pressure was to broaden the lines and to bring out the reversals. However this was not always the case, as it was possible to obtain with cadmium, for example, lines of about the same width with and without pressure; while in the case of some elements, as platinum and osmium, the lines were often narrower at high than at atmospheric pressure. The lines of the carbon bands were brought out more strongly by pressure, but, as already stated, they never showed much if any shift, which fact furnished conclusive evidence that the shift of other lines was not due to a disturbance of the apparatus, since they were all photographed simultaneously on the same plate, the lines of the carbon bands never being appreciably displaced while those of other elements were.

This displacement, or shift, varied greatly for different elements, but in the case of any one, with a single exception to be mentioned below, it was approximately proportional to the wave-length. The most conclusive evidence of this proportionality was furnished by lines of different orders of spectra that appeared on the same plate. Thus ultra-violet lines of the third order were often found on the same plate with the lines of the second of longer wave-length, but the measured shifts of the lines of the same element were approximately the same, and since the wave-length of a line of the third order is to that of one of the second that occurs at the same place as two to three, while the dispersion in the third order is to that in the second as three to two, it follows that constancy of measured shift means that it is proportional to wave-length. For the sake of comparison it was found advisable to reduce the shifts of all lines to what they would be at wave-length 4000, in the neighborhood of which most of our work was done. This reduction consisted of course in multiplying the measured shift of any line by the ratio of 4000 to its wave-length. The exception referred to above is that of calcium. The lines H and K, among others, as shown by Table I., shift only about half as much as *g* and the group at wave-length 5600. That *g* should differ in this respect from H and K is not very surprising, since it is known to differ greatly from them in many other respects. According to Lockyer[1] it is the "longest line" of the calcium spectrum; that is, it occurs at the greatest range of temperature, even at that of an ordinary flame, while the H and K do not appear at temperatures much below that of the electric arc.

All our measurements showed that the shifts were invariably towards the less refrangible, *i. e.*, the red end of the spectrum, and that they were directly proportional, not only to the wave-lengths, but also to the excess of pressure above one atmosphere. It was found impossible, owing to the minuteness of the shift per atmosphere, and to the fact that our apparatus was not designed for vacuum work, to determine whether the same law holds for very low pressures. If it does, then about 8 per cent. of the differences between Professors Rowland and Michelson's determinations of the wave-lengths of the cadmium lines is accounted for. It is even possible that, as a vacuum is very nearly approached, the position of the lines may become much more sensitive to changes of pressure. Indeed, this is in a measure suggested by the results Schumann[2] obtained with the hydrogen line $H\beta$. This, of course, might account not only for 8 per cent. of, but, excepting minute and unavoidable errors, for the whole of the differences between Professors Rowland and Michelson's measurements.

It should be stated that in some cases the values obtained for the shifts may have been due in a measure to unsymmetrical broadening; but this has certainly not led to much error, since, as already stated, only those lines were used which could be accurately measured, that is, those which were either comparatively narrow or else reversed.

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[1] *Chemistry of the Sun.*

[2] *A. and A.* 12, 159, 1893.

TABLE I.

Element	Pressure	4¼	4¾	6	7	7½	8	9	9¼	9¾	10	10¼	10½	10¾	11	11¼	11½	11¾	12¼	12½	12¾	13	13½	14	14½
Fe	3997.547	..	..	..	..	..	..	..	..	..	..	..	..	..	..	29 29	..	..	..	..	..	..	..	..	..
"	4005.408	..	..	..	15 15	..	..	..	..	..	23 23	..	..	..	32 32	..	..	..	..	..	..	..	..	..	..
"	4009.864	..	..	..	..	..	..	..	..	..	18 18	..	..	..	..	..	..	..	..	..	..	..	..	..	..
"	4045.975	..	8 8	9 9	..	..	..	..	..	..	..	..	..	..	..	20 20	..	..	..	..	..	..	..	..	..
"	4063.759	..	..	..	..	..	..	..	..	..	..	..	..	..	..	23 23	..	..	..	..	..	..	..	..	..
"	4181.919	..	..	..	..	..	..	..	..	..	26 25	..	..	..	..	..	..	..	..	..	..	..	..	..	..
"	4199.267	..	..	..	..	..	..	..	..	..	25 24	..	..	..	..	..	..	..	..	..	..	..	..	..	..
"	4207.291	..	..	..	..	..	..	..	..	..	18 17	..	..	..	..	..	..	..	..	..	..	..	..	..	..
"	4219.516	..	..	..	..	..	..	..	..	..	18 17	..	..	..	..	..	..	..	..	..	..	..	..	..	..
"	4236.112	..	8 8	..	17 16	..	..	..	..	..	..	..	26 25	..	26 25	..	..	..	..	..	..	..	..	..	..
"	4250.945	..	..	..	11 11	..	..	..	..	..	26 25	..	..	..	31 29	..	..	..	..	35 33	25 24	..	..	34 32	..
"	4271.934	..	8 8	13 12	14 13	..	..	..	..	..	..	..	..	..	25 23	28 26	20 19	..	28 26	23 22	26 24	..	..	30 28	30 28
"	4294.301	..	..	..	..	..	..	..	..	..	25 23	..	..	..	..	..	..	..	..	..	..	..	..	..	..
"	4298.195	..	..	..	..	..	..	..	..	..	26 24	..	..	..	..	..	..	..	..	..	..	..	..	..	..
"	4325.939	..	..	..	..	..	..	..	..	..	..	..	..	..	..	26 24	..	..	26 24	..	32 30	35 32	..	34 31	..

TABLE I.—*Continued.*

Element	Pressure	4¼	4¾	6	7	7½	8	9	9¼	9¾	10	10¼	10½	10¾	11	11¼	11½	11¾	12¼	12½	12¾	13	13½	14	14½
Fe	4377.948	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	21 19	..	..	..	..	..	..	..	..
"	4382.928	..	..	..	..	..	..	..	..	17 16	24 22	..	..	..	..	..	..	..	26 24	..	27 25	35 32	..	..	31 28
"	4383.720	..	..	..	..	..	..	..	..	17 16	..	..	..	..	..	..	28 26	..	..	..	..	..	..	..	..
"	4404.927	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	23 21	..	..	..	..	..	..	..	..
"	Average for iron	..	8 8	11 11	14 14	..	..	..	..	17 16	23 22	..	26 25	..	29 27	25 24	23 21	..	27 25	29 28	28 26	35 32	..	32 30	32 29
Ni	3391.180	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	14 17	..	..	..	..	..
"	3413.637	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	19 23	..	..	..	..	..
"	3414.092	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	19 23	..	..	..	..	..
"	3437.447	..	..	..	..	..	..	..	..	20 23	..	..	..	..	..	..	..	..	..	..	..	..	..	..	34 39
"	3458.606	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	27 31	..	..	..	..	29 33
"	3461.322	..	..	..	..	..	..	..	..	16 18	..	..	..	..	..	..	..	..	..	23 25	..	..	..	..	..
"	3500.993	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	24 27	..	..	..	..	35 40
"	3515.207	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	34 38	..	..	..	..	41 45
"	3524.677	..	..	..	..	..	..	..	..		..	..	..	..	..	..	..	..	..	30 35	..	..	..	..	..
"	5155.937	..	..	..	..	..	..	..	..	24 18	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

Element	Pressure	4¼	4¾	6	7	7½	8	9	9¼	9¾	10	10¼	10½	10¾	11	11¼	11½	11¾	12¼	12½	12¾	13	13½	14	14½
Ni	Average for nickel..........	..	..	..	..	..	..	..	..	20 20	..	..	..	..	..	..	..	..	..	24 26	..	..	..	..	35 39
Co	3354.515	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	19 23	..	..	..	..	33 39
"	3361.413	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	18 22	..	..	..	..	..
"	3395.016	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	20 24	..	..	..	..	22 26
"	3405.255	..	..	..	..	..	..	..	..	17 20	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
"	3409.336	..	..	..	..	..	..	..	..	14 16	..	..	..	..	..	..	..	..	..	..	..	..	..	..	23 27
"	3417.384	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	23 27	..	..	..	..	29 34
"	3461.326	..	..	..	..	..	..	..	..	18 21	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
"	4121.476	..	..	..	..	..	..	..	..	..	..	..	..	..	..	20 19	..	..	..	..	..	..	..	..	..
"	Average for cobalt..........	..	..	..	..	..	..	..	..	16 19	..	..	..	..	..	20 19	..	..	..	20 24	..	..	..	..	27 32
Mn	4018.269	..	..	13 13	12 12	..	..	..	..	..	..	..	..	..	..	..	..	..	..	32 32	27 27	..	..	37 37	..
"	4026.583	..	8 8	..	..	..	..	..	..	..	..	..	..	..	17 17	..	..	..	..	..	..	..	..	..	..
"	4030.947	..	..	..	..	..	..	..	..	..	..	..	..	..	..	19 19	..	..	..	..	33 33	..	..	34 34	..
"	4035.883	..	8 8	18 18	13 13	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	26 26	..	..	32 32	..
"	4061.881	..	..	..	..	..	..	..	..	..	..	..	..	..	..	20 20	..	..	..	..	..	..	..	..	..

TABLE I.—*Continued.*

Element	Pressure	4¼	4¾	6	7	7½	8	9	9¼	9¾	10	10¼	10½	10¾	11	11¼	11½	11¾	12¼	12½	12¾	13	13½	14	14½
Mn	4235.298	..	10 10	..	22 21	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
"	4235.450	..	8 8	..	18 17	..	..	..	..	..	..	..	27 25	..	37 34	..	..	..	..	..	32 29	..	..	36 33	..
"	4239.890	..	13 12	21 20	..	..	..	..	..	..	..	..	..	..	..	..	31 29	..	..	48 45	..	..	..	47 44	..
"	4257.815	..	14 13	21 20	22 21	..	..	..	..	..	..	..	25 23	..	39 36	..	..	..	..	..	47 43	..	..	47 43	..
"	4266.081	..	14 13	20 19	22 21	..	..	..	..	..	..	..	38 35	..	..	..	40 37	..	..	41 38	40 37	..	..	46 43	..
"	4281.257	..	10 9	..	21 20	..	..	..	..	..	..	..	37 34	..	43 40	..	39 36	..	..	41 38	38 35	..	..	44 41	..
"	4284.223	..	12 11	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
"	Average for manganese	..	11 10	19 18	19 18	..	..	..	..	..	..	..	32 30	..	34 32	20 20	37 34	..	..	40 38	35 33	..	..	40 38	..
Cr	3886.942	..	4 4	..	..	..	..	..	..	..	..	..	..	..	26 27	..	..	..	..	..	..	..	..	36 37	..
"	3919.309	..	..	16 16	..	..	..	..	..	..	..	..	..	..	20 20	..	..	..	..	12 12	..	..	..	29 30	..
"	3941.637	..	7 7	..	..	..	..	..	..	..	..	..	..	..	33 34	..	..	..	..	..	..	..	..	32 33	..
"	3963.831	..	7 7	12 12	16 16	..	..	..	..	..	..	..	23 23	..	27 27	..	..	..	..	36 36	..	..	..	47 47	..
"	3976.839	..	14 14	12 12	12 12	..	..	..	..	25 25	..	..	..	..	28 28	..	..	..	..	..	..	..	..	38 38	..
"	3984.059	..	12 12	..	..	..	..	..	..	..	..	..	..	..	34 34	..	..	..	..	..	..	..	..	49 49	..
"	4026.318	..	..	..	19 10	..	..	..	..	..	..	..	..	..	..	..	..	..	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	..

TABLE I.—Continued.

Element	Pressure	4¼	4¾	6	7	7½	8	9	9¼	9¾	10	10¼	10½	10¾	11	11¼	11½	11¾	12¼	12½	12¾	13	13½	14	14½
Cr	4254.505	..	3 3	9 9	19 18	..	..	..	..	..	..	..	..	..	26 24	..	..	..	..	..	..	..	..	26 24	30 28
"	4266.894	..	..	..	..	..	..	..	..	..	17 16	..	..	..	..	..	..	..	..	..	..	..	..	..	..
"	4274.958	..	14 13	11 10	..	..	..	..	..	..	..	..	..	..	31 29	..	..	..	24 22	..	..	..	..	40 38	31 29
"	4280.556	..	..	..	..	..	..	..	..	..	..	..	..	..	30 28	..	23 22	..	..	..	..	..	..	..	..
"	4289.885	..	..	..	..	..	..	..	..	..	..	..	..	..	34 32	..	..	..	..	..	..	..	..	41 44	..
"	Average for cromium	.	9 9	14 13	16 15	..	..	..	..	25 25	17 16	..	23 23	..	29 28	..	23 22	..	24 22	24 24	..	..	..	38 37	31 29
Pb	3639.728	..	.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	63 70	..	..
"	3683.622	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	70 76	..	..
"	4058.041	..	..	..	..	..	..	..	..	..	..	..	..	..	55 54	49 48	..	..	..	..	..	..	..	..	..
"	Average for lead	..	..	..	..	..	..	..	..	..	..	..	..	..	55 54	49 48	..	..	..	..	..	..	67 73	..	..
Sn	3175.12	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	48 59	..	..	..	..	54 68
"	3262.44	..	..	..	..	..	..	..	..	37 46	..	..	..	..	..	..	..	..	..	47 58	..	44 55	..	..	51 63
"	3330.71	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	44 55	..	..	..	..	64 77
"	Average for tin	..	..	..	..	..	..	..	..	37 46	..	..	..	..	..	..	..	..	..	45 57	..	44 55	..	..	56 69
Bi	2898.08	..	..	..	..	..	..	..	..	..	26 35	..	..	..	..	..	..	..	..	..	..	..	..	..	..

TABLE I.—*Continued.*

Element	Pressure	4¼	4¾	6	7	7½	8	9	9¼	9¾	10	10¼	10½	10¾	11	11¼	11½	11¾	12¼	12½	12¾	13	13½	14	14½
Bi	2989.15	..	..	..	..	..	..	..	..	..	34 45	..	..	..	..	..	..	..	..	..	..	..	..	..	..
"	3397.31	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	48 57	..	..
"	Average for bismuth	..	..	..	..	..	..	..	..	..	30 40	..	..	..	..	..	..	..	..	..	..	..	48 57	..	..
Tl	3519.342	..	..	..	..	..	..	..	..	37 41	..	..	..	..	..	..	..	..	..	..	..	..	65 73	..	64 72
In	4102.000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	69 68	..	..	..	..	..	..	..	..	..
"	4511.345	..	..	..	..	..	..	..	..	73 65	..	81 72	..	..	..	..	..	..	102 90	..	..	..	..	..	125 111
Al	3944.114	..	17 17	29 29	..	..	..	..	..	..	..	..	..	44 45	..	..	..	49 50	..	..	48 49	..	..	67 68	..
"	3961.674	17 17	25 25	26 26	37 37	36 36	..	..	..	..	..	..	44 45	40 41	..	..	..	57 58	..	..	52 53	..	..	76 77	..
"	Average for aluminium	17 17	21 21	28 28	37 37	36 36	..	..	..	..	..	..	44 45	42 43	..	..	..	53 54	..	..	50 51	..	..	72 73	..
Pt	2830.41	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	16 22	..	..	..
"	2893.98	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	14 20	..	..	..
"	2897.99	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	12 17	..	..	..
"	2929.91	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	12 16	17 24	..	..	..
"	2998.079	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	15 20	..	17 23	18 25	..	..	13 18
"	3042.745	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	18 25	..	..	23 [illegible]

Element	Pressure	4¼	4¾	6	7	7½	8	9	9¼	9¾	10	10¼	10½	10¾	11	11¼	11½	11¾	12¼	12½	12¾	13	13½	14	14½
Pt	3064.824	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	16 21
"	4442.723	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	25 23	..	..	31 28	..	..	..
"	Average for platinum	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	20 21	..	15 20	18 23	..	..	18 24
Os	4260.993	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	17 16	..	..	..
"	4420.633	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	22 20	18 16	..	..	..
Rh	4211.6	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	45 43	..	..	..
"	4375.0	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	31 28	..	38 34	45 41	..	..	37 34
Pd	3373.139	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	33 39	..	..
"	3404.725	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	40 47	..	..
"	3421.367	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	38 44	..	..
"	3433.578	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	31 36	..	..
"	3441.539	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	31 36	..	..
"	3460.884	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	27 31	..	..
"	3481.300	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	25 29	..	..
"	3489.915	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	30 34	..	..

TABLE I.—*Continued.*

Element	Pressure	4¼	4¾	6	7	7½	8	9	9¼	9¾	10	10¼	10½	10¾	11	11¼	11½	11¾	12¼	12½	12¾	13	13½	14	14½
Pd	3609.696	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	44 48	..	..
"	3634.841	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	41 45	..	..
"	3690.483	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	28 31	..	..
"	Average for palladium	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	33 38	..	..
Y	3950.497	..	5 5	7 7	..	..	..	..	..	..	..	..	..	..	15 15	..	..	..	..	17 17	..	14 14	..	..	..
"	3982.742	..	4 4	..	4 4	..	..	..	..	..	..	..	..	..	..	..	..	..	..	17 17	..	18 18	..	..	..
Bo	2496.867	..	..	..	..	..	19 30	23 37	25 40	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
"	2497.821	..	..	..	..	..	18 30	22 35	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
C	2478.661	..	..	..	..	..	..	20 32	21 33	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Cu	3247.680	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	25 30	28 33	..	..	28 33	..	..
"	3274.092	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	20 25	32 38	..	30 36	36 41	..	..
Ag	3280.80	..	..	..	..	..	..	..	..	28 33	..	..	..	..	..	..	..	..	..	32 39	..	..	..	..	..
"	3383.00	..	..	..	..	..	..	..	..	34 40	..	..	..	..	..	..	..	..	..	27 32	..	32 38	..	..	..
Ca	3933.825 K	..	..	..	..	..	..	..	..	..	..	..	..	..	14 14	20 20	..	..	..	23 23	15 15	..	..	..	..
"	3968.625 H	..	..	..	..	..	..	..	..	..	..	22 22	..	..	..	30 30	..	..	33 33	..	17 17	..	..	..	..

TABLE I.—*Continued.*

Element	Pressure	4¼	4¾	6	7	7½	8	9	9¼	9¾	10	10¼	10½	10¾	11	11¼	11½	11¾	12¼	12½	12¾	13	13½	14	14½
Ca	4283.169	..	..	18 17	..	..	..	..	..	..	..	..	..	..	31 29	..	..	..	..	..	28 26	..	..	..	..
"	4289.525	..	..	18 17	..	..	..	..	..	..	..	..	..	..	22 21	..	..	..	..	..	43 40	..	..	..	..
"	4299.149	..	8 7	13 12	..	..	..	..	..	..	..	..	..	..	37 34	..	..	..	..	..	34 32	..	..	25 23	..
'	4302.692	..	..	12 11	..	..	..	..	..	..	..	..	..	..	28 26	..	..	..	..	..	30 28	..	..	25 23	25 23
"	Average for H and K group	..	8 7	15 14	..	..	..	..	..	..	..	22 22	..	..	26 25	25 25	..	..	33 33	23 23	28 26	..	..	25 23	25 23
"	4226.904 g	..	..	..	..	..	..	..	..	..	..	..	..	..	..	49 46	..	..	51 48	..	..	56 53	..	..	87 82
"	5588.985	..	..	..	..	..	..	..	..	..	..	..	..	..	..	70 50	..	..	..	..	..	..	..	..	..
"	5594.691	..	..	..	..	..	..	..	..	..	..	..	..	..	..	72 52	..	..	..	..	..	..	..	..	..
"	5598.711	..	..	..	..	..	..	..	..	..	..	..	..	..	..	63 45	..	..	..	..	..	..	..	..	..
"	5603.083	..	..	..	..	56 40	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
"	Average for *g* group	..	..	..	..	56 40	..	..	..	..	..	..	..	..	..	64 48	..	..	51 48	..	..	56 53	..	..	81 82
Zn	4680.317	..	..	..	..	..	..	..	..	68 58	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
"	4722.342	..	..	..	..	..	..	..	..	62 52	..	..	..	..	..	..	..	..	58 49	..	..	..	63 53	63 53	..
"	4810.724	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	67 56	..	..	..	74 62	..	..
"	Average for zinc	..	..	..	..	..	..	..	..	65 55	..	..	..	..	..	..	..	..	63 53	..	..	..	69 58	..	..

TABLE I.—*Continued.*

Element	Pressure	4¼	4¾	6	7	7½	8	9	9¼	9¾	10	10¼	10½	10¾	11	11¼	11½	11¾	12¼	12½	12¾	13	13½	14	14½
Cd	4678.347	..	..	..	..	..	..	54 46	79 67	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
"	4800.080	..	..	..	..	..	43 36	48 40	70 58	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
"	5086.078	..	..	..	53 42	59 46	63 50	67 52	80 63	..	..	90 71	..	..	..	..	..	..	..	..	..	..	..	..	..
	Average for cadmium	..	..	..	53 42	59 46	53 43	85 69	76 63	..	..	90 71	..	..	..	..	..	..	..	..	..	..	..	..	..

DESCRIPTION OF TABLES AND CURVES.

Results of the measurements are given in Table I., in which the upper numbers in the line of each wave-length are the observed shifts in thousandths of an Ångström unit, and the lower their values when reduced to wave-length 4000. The curves (Plates XII. and XIII.), which are all plotted to the same scale from the averages of the table, have for abscissæ the reduced shifts, and for ordinates the pressures in atmospheres. The wave-lengths are taken, as far as possible, from Professor Rowland's table of solar wave-lengths, now in process of publication in the ASTROPHYSICAL JOURNAL. In some cases we used a former table of his published in *Astronomy and Astrophysics.*[1] The wave-lengths of osmium, palladium and platinum were taken from a table recently completed by Professor Rowland and Dr. Tatnall,[2] those of bismuth tin and silver were obtained from a table by Kayser and Runge.[3]

Some idea of the character of the photographs may be obtained from the accompanying plate (Plate X.) at the top of which is a scale of wave-lengths divided into half Ångström units. I. and II. are portions of

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[1] *A. and A.* 12, 1893.

[2] *Ap. J.* October, 1895.

[3] *Abh. d. K. Akad. d. W. Berlin*, 1892–3.

PLATE XII.

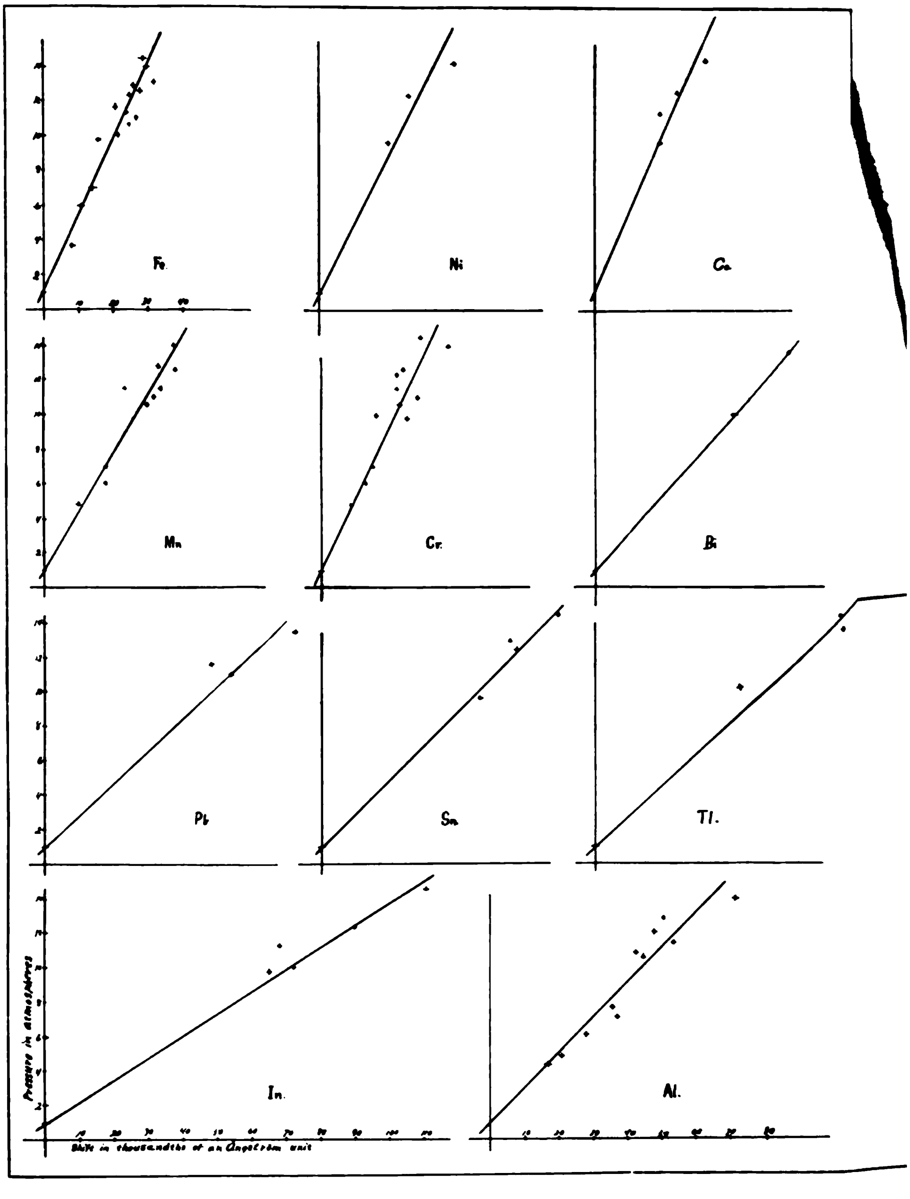
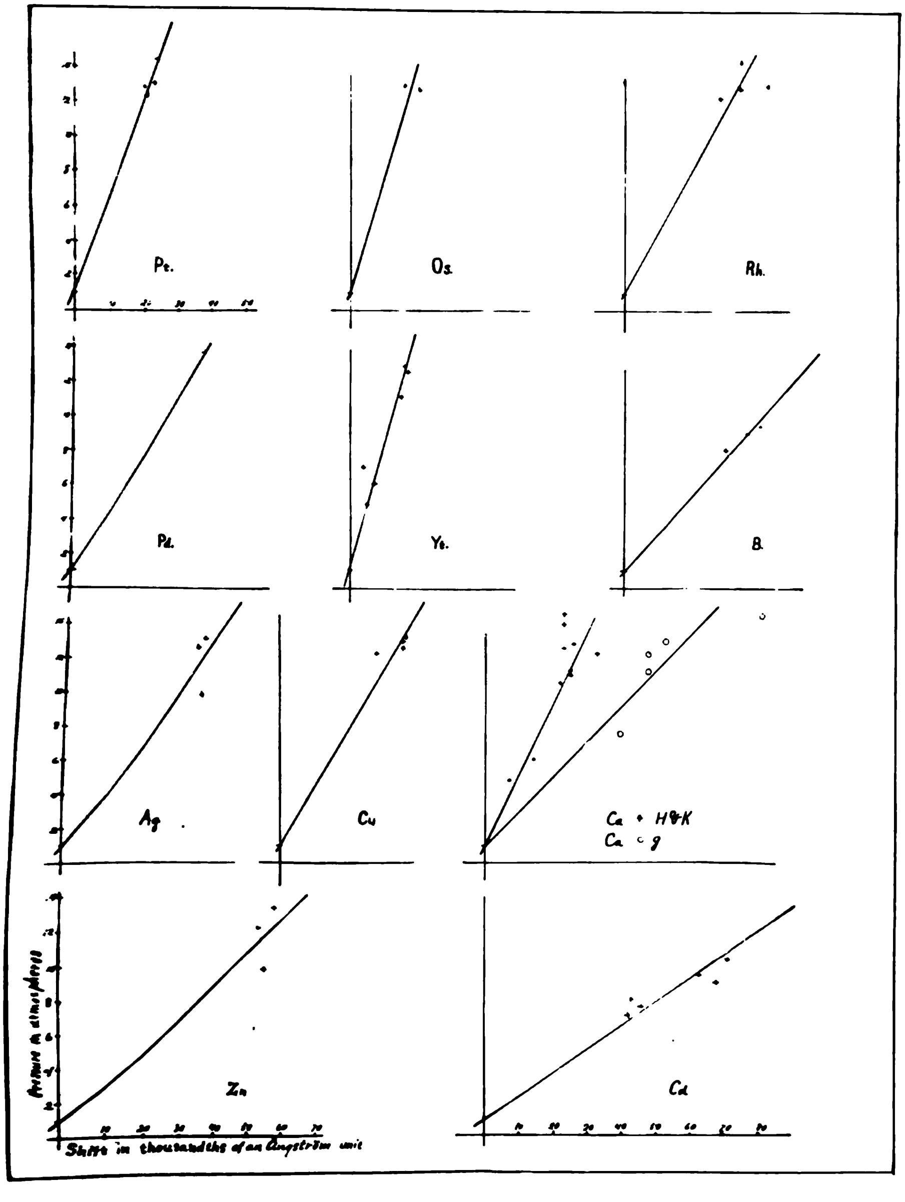

Fe.
Ni
Co
Mn
Cr.
Bi
Pb
Sn
Tl.
In.
Al.
Pressure in atmospheres
2
4
6
8
10
12
14
10
20
30
40
50
60
70
80
90
100
110
Shift in thousandths of an Angstrom unit

PLATE XIII.


Pt.
Os.
Rh.
Pd.
Yt.
B.
Ag
Cu
Ca • H&K
Ca ○ g
Zn
Cd
Pressure in atmospheres
Shift in thousandths of an Angström unit
10
20
30
40
50
60
70
2
4
6
8
10
12
14

the same negative, the pressures when the outer portions and middle strip were taken being respectively one and twelve and one-quarter atmospheres. I. shows the rhodium line of wave-length 4211, a portion of the solar spectrum, part of a carbon band and the calcium line *g*, while II. shows the indium line of wave-length 4511. III., the outer and middle portions of which were taken when the pressures were respectively one and eleven and one-quarter atmospheres, shows the aluminium line of wave-length 3961, the calcium line H and the lead line of wave-length 4058. IV. is from a negative showing the cadmium line of wave-length 4800, and a portion of the solar spectrum. In this case the middle strip was obtained when the arc was under a pressure of but one atmosphere, and the outer portions when the arc was under a pressure of nine atmospheres. V. is taken from a negative that was obtained when the arc was formed between a carbon negative and an iron positive pole, the pressures when the outer portions and middle strip were taken being respectively one and ten atmospheres. This photograph shows that, when the lines are close together, the effect of pressure is to form a practically continuous spectrum with only reversed lines, thus in a measure approaching the condition of the solar spectrum.

THEORETICAL RELATIONS.

In considering these numerical values of the shifts for different elements certain mathematical relations were discovered.

It was first noticed that forming for various elements the product of the cube root of the "atomic volume" and the coefficient of linear expansion of the substance in the solid form, certain numbers were obtained whose ratios were the same as those of the shift for the respective elements. The atomic volume is the ratio of the atomic weight to the density for any standard temperature; and its cube root was taken because the wave-length of any series of waves produced by a body varies directly as its linear dimensions. In our figures the atomic volume and the coefficient of expansion both refer to 40°C, and the shift is that which corresponds to wave-length 4000. The agreement of the two sets of figures may be seen in Table II., fifth and sixth columns.

Raoul Pictet[1] has used a similar expression in his formula for deducing the melting points of the metals. He finds that the continued product of the absolute temperature of the melting point, the linear coefficient of expansion, and the cube root of the atomic volume is nearly the same for all the metals except bismuth.

The coefficient of expansion of a substance is, in a certain way, an inverse measure of the resistance of the atom to external forces; and without implying that shift is a direct temperature effect it is not unreasonable to suppose that the coefficient of expansion multiplied by a linear dimension of the atomic volume may be proportional to the change in the wave-length of the light emitted, since this product would be the actual change in the linear dimensions of the atomic volume, if there was any change in volume.

Table II. shows the connection of our work with that of M. Pictet, the eighth column giving the quotient of a constant, *i. e.*, 48600—divided by the absolute temperature of the melting point. The number 48600 was taken so as to reduce his results to numbers comparable with the shift at twelve atmospheres pressure, that for iron being made to coincide with the "theoretical value" $a\sqrt[3]{V}$. This table shows that the shift is about as near the "theoretical value" as the melting point, and this would indicate that the product of the shift by the absolute temperature of the melting point is (with the exception of bismuth) nearly constant, or that the shift is inversely proportional to the absolute temperature of the melting point.

According to the above considerations the shift of the lines of mercury ought to be very large. We made a number of attempts to photograph the mercury lines but obtained no good results, as the lines, though showing a large displacement, were too hazy and diffuse to admit of accurate measurement. The work shows such close agreement between the shift and $a\sqrt[3]{V}$ that the coefficient of expansion of the elements in the solid state at 40°C. may be calculated with some degree of probability if the atomic volume is known. On the above assumption the undetermined linear coefficients of expansion of the following elements would be:

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[1] *C. R.* **88**, 855, 1879.

For Manganese	.0000173
For Chromium	.0000165
For Calcium (*g* line)	.0000184
For Boron	.0000309

In the case of calcium the calculation is based on the shift of the *g* line at wave-length 4226. The fact that the lines H and K have a different shift from *g* seems to agree with the theory that at very high temperatures some substances are dissociated.

TABLE II.

	W_1	V_1	a_2	$a\sqrt[3]{V}$	S	T_1	$\frac{48600}{T}$	$\sqrt[3]{W}$
	......	....	.0000	....	..	....	....	....
Fe	55.9	7.2	1210	23.3	25	2080	23.3	3.82
Ni	58.6	6.7	1279	24.	28	1870	26.5	3.80
Co	58.6	6.9	1236	23.6	24	2070	24.	3.88
Mn	54.8	6.9	....	....	33	2170	22.9	3.80
Cr	52.45	7.7	....	....	26	....	....	3.74
Bi	207.3	21.1	1621	44.7	49	538	90.3	5.92
Pb	206.4	18.1	2924	76.9	60	605	80.3	5.91
Sn	118.8	16.3	2234	58.4	55	503	96.6	4.92
Tl	203.7	17.2	3121	78.	61	563	86.3	5.89
In	113.6	15.3	4170	103.5	88	449	108.3	4.84
Al	27.04	10.6	2313	50.6	55	1123	43.3	3.00
Pt	194.3	9 1	0899	18.5	20	2050	23.7	5.79
Os	190.3	8.5	0657	13.4	17	2770	17.5	5.76
Rh	104.1	8.6	0850	17.4	30	2270	21.4	4.70
Pd	106.35	9.2	1176	24.7	33	1775	27.4	4.74
Y	88.9	....	....	....	15	....	....	4.46
B	10.9	4.	....	....	49	....	....	2.22
C	......	....	0118	2.7	..	....	....	....
	11.97	3.6	0540	8.2	0	....	....	2.29
Ag	107.7	10.2	1921	42.2	38	1230	39.5	4.76
Cu	63.18	7 1	1678	32.5	33	1330	36.5	3.98
Ca	39.91	25.4	....	....	27	....	....	3.42
Ca	39.91	25.4	....	....	54	....	....	3.42
Zn	65.10	9.1	2918	61.2	57	676	71.9	4.02
Cd	111.7	12.9	3069	75.6	80	593	82.	4.82

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[1] NERNST, *Theoretical Chemistry.*

[2] FIZEAU at 40°C. *Physikalish-Chem. Tabellen von Landolt und Börnstein.*

DESCRIPTION OF TABLE II.

The column marked W gives the atomic weights of the elements. Under V is given the atomic volume at 40°C., and under α the linear coefficient of expansion. In all cases this is from Fizeau's results at 40°C. The column marked $\alpha\sqrt[3]{V}$ gives the product of the linear coefficient of expansion by the cube root of the atomic volume multipled by 10^6. Under S is found the reduced shift at twelve atmospheres pressure. The column marked T gives the absolute temperature of the melting point and the next column marked $\frac{48600}{T}$ gives the quotient indicated. The last column gives the cube roots of the atomic weights.

Besides the relations already described a connection between the atomic weights and the shifts of the corresponding elements was also found. While this connection is not perfect, it nevertheless seems altogether too general to be merely accidental. The relation is as follows: Given the shifts of the lines of any element, the shifts of those of other elements belonging to the same Mendelejeff group, can be found on the supposition that they are to each other as the cube roots of the respective atomic weights. This is shown in the first part of Table III. in which the standard shifts, assumed to be correct, have all been determined by experiment and tabulated in Table II.

DESCRIPTION OF TABLE III.

Each horizontal row of Table III. shows the comparison between the observed shift of the lines of one element and that calculated for them from the observed shift of the lines of another element of the same group.

It will be observed that the calculated values agree almost exactly with the observed except in the case of boron, which, besides differing from the other elements in being non-metallic, furnished only two lines that could be measured, and even these were not very good.

Beyond the fact that atoms are exceedingly minute, scarcely anything is known of their actual size, nor is anything at all

TABLE III.

Showing shifts in thousandths of an Ångström unit for twelve atmospheres and wave-length 4000.

Standard			Calculated	Observed
Cu	33	Ag	39	38
Cd	80	Zn	66	57
Cd	80	Ca (*g*)	56	54
Al	55	In	89	88
Al	55	B	36	49
Sn	55	Pb	66	60
Co	24	Rh	29	30
Ni	28	Pd	34	33
Cd	80	Ca (H and K)	28	27
Al	55	Tl	54	61
Al	55	Y	41	15
Fe	25	Os	19	17
Ni	28	Pt	21	20

definitely known as to their density, and therefore, for all we know, the atoms of the same group may have either the same or different densities. If, however, they have the same density then (unless they differ in shape) their linear dimensions are to each other as the cube roots of their atomic weights; and consequently our measurements would mean that the shifts of elements of the same group have the same relations to each other as the linear dimensions of their atoms. Or, on the other hand, if it be accepted that the shifts are directly proportioned to the linear dimensions of the vibrating particles, then it would follow that the atomic density is constant for the elements of any group.

The lines of a few elements, yttrium, osmium, platinum, thallium and calcium (H and K) do not give shifts which at first seem to agree with this rule. If, however, we assume that these substances dissociate in the arc into eight equal parts (possibly dividing along three intersecting symmetrical planes and thus for many configurations giving the same shape to the parts as that of the original) then their observed shifts and those calculated using one-eighth of the atomic weights agree within experimental errors, except in the case of yttrium. This is shown by the second part of Table III. Of course, if yttrium were assumed to dissociate a second time, in the way explained above, its calculated shift would be about twenty, which is within experimental error of its observed shift fifteen, but, as the yttrium earths still present puzzling difficulties, it does not seem worth while to offer regarding their lines any speculations, which possibly have already gone too far in regard to the behavior of other lines.

While the shifts of the lines due to elements of different groups (group used in the same sense that it is in the Mendelejeff periodic law) differ from each other greatly, it is nevertheless possible, in most cases, at least, to pass from one group to another by means of the ratios of the coefficients of expansion of elements of different groups but of the same series. Thus within experimental errors the ratio of the coefficients of expansion of copper to zinc, of silver to indium and tin, of cadmium to indium and tin, and of aluminium to iron, nickel and cobalt, is in every case equal to the corresponding ratio of shifts.

Bismuth, chromium and manganese are not put in Table III. because they are the only substances of their respective groups examined, and thus there is nothing with which to compare them.

Several unsuccessful attempts were made to photograph the ultra-violet lines of magnesium under pressure, in hope of obtaining the shifts of lines of the different series which occur at about wave-length 2750. We failed because the fumes generated by the arc absorbed the light, for in all cases the ultra-violet light is more absorbed than that of longer wave-length. In almost all our work we were limited to short exposures from this cause.

As noted above the lines of the carbon bands showed no appreciable shift with the pressures employed. Indeed in some cases they were used as "base lines" from which the shift of other lines was obtained. The single carbon line at wave-length 2478 is an exception as its shift as measured on several plates is about 0.046 of an Ångström unit at twelve atmospheres pressure. In Table II. the values of a in the case of carbon are those given for diamond at 40°C and also for gas carbon, the upper number being for diamond and the lower for gas carbon.

Work was begun on this investigation in February 1895, and a preliminary paper on it was read at the Springfield meeting of the American Association for the Advancement of Science in September of this year.

Our work was done under the supervision of the directors of the Physical Laboratory, Professor Rowland and Dr. Ames. We would especially acknowledge our indebtedness to Dr. Ames for his assistance, as many of the points brought out are the direct results of his suggestions. Our thanks are also due to Mr. Jewell for assistance in the choice and measurement of the lines, and to Dr. Tatnall for kindly sending us his measurements of the palladium lines which are not yet published.

JOHNS HOPKINS UNIVERSITY.
December 12, 1895.

NOTE ON THE PRESSURE OF THE "REVERSIN(LAYER" OF THE SOLAR ATMOSPHERE.

By L. E. Jewell, J. F. Mohler and W. J. Humphreys.

The investigation of the effect of pressure on the wa lengths of the lines of arc-spectra,[1] together with the obse tion that many lines of the solar spectrum do not quite coin with the corresponding lines of arc-spectra at atmosph pressure,[2] seems to furnish a method of determining the p sures of the solar atmosphere where the Fraunhofer lines produced.

The difference between the wave-lengths of the lines ordinary arc-spectra and those of the Sun is most marked in case of those that are strong in the solar spectrum, and at same time strongly reversed in the arc. Most of the lines m tioned below are of this character.

Assuming that the solar atmosphere is comparatively qu cent, and that the displacements of the lines in the solar sp trum, referred to the arc at atmospheric pressure, and their sh in the arc at different pressures (referred to the same standa are both due to pressure alone, we find, on comparing these placements and shifts, the results shown in the table on op site page.

It will be noticed that two pressures, corresponding to groups of lines, are given for the reversing layer of calci This comes from the difference in the shifts of these lines in spectrum of the arc under pressure; but, excepting the l H, K, and *g*, the two groups present the same appearance in solar spectrum.

The lines H and K are peculiar in many respects, and often displaced much more than any other calcium lines. T positions, however, relative to other solar lines are found to

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[1] See page 114.

[2] See page 82.

Element	Wave-length	Pressure (in Atmospheres) of Reversing Layer
Al	3944.160	2
"	3961.674	
Si	3905.660	4
Ca	4283.169	6
"	4289.525	
"	4299.149	
"	4302.692	
"	4226.904	3
"	5588.985	
"	5594.691	
"	5598.711	
Cr	Several lines	5
Mn	" "	6
Fe	" "	7
Ni	" "	7
Cu	" "	7
Co	" "	4

different on different plates, and this difference in position is connected with certain peculiarities in appearance. Besides they occur in the chromosphere and always in prominences, where the pressure must be comparatively small. The narrowness of the central line in both H and K likewise indicates a comparatively low pressure for their final absorption. These facts, especially the difference in the positions of H and K on different plates, and their occurrence at great altitudes, make it appear probable that their displacements may be accounted for, at least in part, by motion in the line of sight. Their general appearance seems to indicate an enormous amount of material present throughout a great range of elevation and pressure, while the appearance of *g* indicates only a small amount of material with a limited range of elevation and pressure. The peculiarities of these lines are very marked, the causes of which are by no means perfectly understood, consequently a further discussion of them would be out of place in the present note.

These observations, as may be seen from the table, seem to indicate that possibly the upper limits of the reversing layers of the different elements in the solar atmosphere are arranged somewhat in the order of their atomic weights, those of heavier atomic weights being at greater pressures, and consequently smaller elevations. This does not mean that these elements are not present at greater depths in the Sun, but that they do not occur to an appreciable extent at higher elevations where the pressure is less than that given by the method of comparison explained in this note.

PHYSICAL LABORATORY, JOHNS HOPKINS UNIVERSITY,
December 23, 1895

RELIMINARY TABLE OF SOLAR SPECTRUM WAVE-LENGTHS. XI.

By HENRY A. ROWLAND.

ngth	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
		0000	5922.578	A (wv)	0
s	Fe	4	5922.735	A (wv)	2
	-, A (wv)	6	5922.930	A (wv)	0
	A?	0000	5923.235		0000
		0000	5923.405	A (wv)	00
	A (wv)	1	5923.500		0000
		0000	5923.702		0000
	A (wv)	1	5923.865	A (wv)	1
	A (wv)	1	5924.040	A (wv)	2
	A (wv)	000	5924.180		000
	A (wv)	00	5924.490	A (wv)	4
s	Fe	3	5024.787		0000
		0000	5924.975	A (wv)	000
	A (wv)	0	5925.082		0000
	A (wv),-	000	5925.220	A (wv)	2
	A?	000	5925.460		0000
	-, A?	0000 N	5925.799	A?	0000
	A (wv)	0	5926.048		0000
		0000	5926.244		0000
		0000	5926.418		0000
	A (wv)	00 d	5926.835	A (wv)	000
	A?	0000	5927.040	A?,-	0000
	A (wv)	4	5927.425		0000
	Ti	0	5927.750		0000
		0000 N	5928.013	Fe	2
	A (wv)	000	5928.280		000
	A (wv)	5	5928.510	A (wv)	2
		0000	5928.740		0000
	A?	0000	5928.890	A?	0000
s	A (wv)	7	5929.056	A (wv)	000
	A?	0000	5929.100		000
	A (wv)	00	5929.350	A (wv)	00
	A?	0000	5929.630	A (wv)	000
	A (wv)	1	5929.898	Fe	2
	A?	0000	5930.145	A?	0000
	A (wv)	00	5930.225		0000
	A?	0000 N	5930.406 s	Fe	6
	A (wv)	0	5930.640		0000
	A?	0000	5930.815	A (wv)	00
	Ti	0	5930.980		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Characte
5931.230	A (wv)	00	5942.635	A (wv)	1
5932.118		0000	5942.789	A (wv)	3
5932.306	A (wv)	5	5942.950		0000
5932.456	A?	0000	5943.120		0000
5932.699	A?	0000	5943.330		0000
5932.998	A (wv)	2	5943.605		000
5933.233	A (wv)	0000	5943.815		00
5933.425		0000	5944.065		0000
5933.670	A?	0000	5944.230		0000
5933.872	A (wv)	000	5944.530	A (wv)	1
5934.024		000	5944.713		0000
5934.140	A (wv)	000	5944.945	A (wv)	1
5934.300	A (wv)	00	5945.230		0000
5934.490		0000	5945.463	A (wv)	00
5934.655		0000	5945.530	A (wv)	00
5934.881 s	Fe	5	5945.865	A (wv)	1
5935.165		0000	5946.104	A?	0000
5935.400	A (wv)	00	5946.223	A (wv)	3
5935.625		000	5946.485	A?	0000
5935.863	A?	0000	5946.685		000
5936.038	A (wv)	0	5946.864	A (wv)	000
5936.278		0000	5947.062	A (wv)	1
5936.428	A?	0000 N	5947.283	A (wv)	2
5937.183		0000	5947.500		0000
5937.345	A (wv)	0000	5947.644	A (wv)	000
5937.523	A (wv)	000	5947.730		00
5937.670	A (wv)	000	5947.955	A?	0000
5938.035		000	5948.195	A?	0000
5938.160	A (wv)	000	5948.452	A (wv)	00
5938.270	A (wv)	0	5948.765 s	Si	6
5938.500	A (wv)	000	5948.995	A (wv)	000
5938.810	A (wv)	00	5949.240	A (wv)	0000
5938.965		0000	5949.390	A (wv)	2
5939.455		0000 N	5949.566	Fe	1
5939.633		0000	5949.794	A (wv)	000
5939.967		0000	5949.880	A (wv),-	000
5940.185	A (wv)	0	5950.040	A (wv)	0
5940.400	A?,-	000	5950.229		0000
5940.640	A (wv)	1	5950.356	A (wv),-	00
5940.875		0000 N	5950.560	A (wv)	0
5941.091	A (wv)	00	5950.688		0000
5941.210		0	5951.070	A?	0000
5941.290	A (wv)	5	5951.181	A (wv)	00
5941.470	A (wv)	000	5951.310		0000
5941.630	A?	0000	5951.440	A (wv)	000
5941.845	A (wv)	2	5951.530	A (wv)	000
5941.985	Ti	00	5951.718	A (wv)	0
5942.220	A?	0000	5952.015		0000
5942.399		0000	5952.406		0000
5942.500	A (wv)	000	5952.578	A?	000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
5952.740		000	5965.163	A (wv)	00
5952.943	Fe	4	5965.370	A?	0000
5953.207		0000 N	5965.543	A?	0000
5953.386	Ti	1	5965.740		0000
5953.583	A?	0000	5966.055	Ti, A?	2
5953.680	A (wv)	00	5966.223		0000
5953.935		0000	5966.430	A (wv)	000
5954.200	A?	000	5966.560	A (wv)	0
5954.595	A (wv)	000	5966.706	A?	0000
5954.906		0000	5966.885	A (wv)	1
5955.170	A (wv)	1	5967.218	A?	000
5955.331		0000	5967.540	A (wv)	00
5955.570		0000	5967.720		0000
5955.890		0000	5967.880		000
5956.039	A (wv)	000	5968.058	A (wv)	2
5956.252	A (wv)	000	5968.280	A (wv)	000
5956.364	A (wv)	0000	5968.495	A (wv)	2
5956.573	A (wv)	0	5968.630		0000
5956.715		0000	5968.882	A?	0000
5956.923 s	Fe	4	5969.260	A (wv)	0
5957.175		0000	5969.510	A?	0000
5957.253		0000	5969.795		000
5957.365	A?	0000	5970.046	A?	0000
5957.790		0000	5970.280	A (wv)	0
5958.098	A (wv)	1	5970.480	A?	000
5958.297		0000	5970.714		0000
5958.460	A (wv),-	1	5970.908	A (wv)	000
5958.565		00	5971.182		0000
5958.840		1	5971.366		0000
5959.025	A?	0000	5971.557	A (wv)	1
5959.380		000	5971.990		0000
5959.535	A?	0000	5972.970		0000
5959.830		000	5973.203		0000
5959.940		000	5973.578		0000
5960.200	A?	0	5973.695		0000
5960.560		0000	5974.094	N	0000
5960.800		0000	5974.495		0
5961.444		0000	5974.812	N	0000
5961.665	A (wv)	0	5975.054		0000
5961.955		0000	5975.330	A (wv)	1
5962.110		0000	5975.413		0000
5962.390	A?	000	5975.575 s	Fe	3
5962.516	A?	0000	5975.820		0000
5962.690	A (wv)	0	5976.046		0000
5962.840		0000	5976.150	A?	000
5963.134		0000	5976.387		0000
5963.326		0000	5976.504		0000
5963.496	A?	000	5976.694	A (wv)	00
5963.790		0000	5976.730	-,A?	0
5964.826		0000	5977.007 s	Fe	4

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
5977.252 s	A (wv)	1 d?	5989.313	A?	0000
5977.513		0000	5989.510	A (wv)	0
5977.655	A (wv)	00 N	5989.788		0000
5978.033	A (wv)	0	5990.290		000
5978.292		0000	5990.595		0000
5978.365	A?	000	5990.830	A (wv)	00
5978.560		0000	5991.070	A (wv)	0
5978.768	Ti	1	5991.237		0000
5979.012		0000	5991.600		2
5979.135		000 N	5991.790		0000
5979.455	A?	0000 N	5992.010		000
5979.527		0000	5992.218	A (wv)	0
5979.915		0000 N d?	5992.409		0000
5980.395	A (wv),-	00	5992.555		0000
5980.740	A (wv)	000	5992.900		0000
5980.965	A?	0000	5993.275	A (wv)	00
5981.043		0000	5993.674		0000
5981.450	A?	00	5993.875		0000
5981.614		0000	5994.135	A (wv)	00
5981.930	A?	0000	5994.563		0000
5982.085		000	5994.756	A (wv)	0
5982.200		0000	5995.491	A?	0000 N
5982.530		000	5995.916		0000
5982.838		0000 N	5996.164		000 N
5983.098	A (wv)	00	5996.247		0000
5983.525	A (wv)	000	5996.445		0000
5983.650		0000	5996.725		0000
5983.908	Fe	5	5996.963	Ni	1
5984.195	A?	000	5997.195		0000
5984.285		0000	5997.438		0000
5984.495		000	5997.578	A (wv)	0
5984.660		0000	5997.826	A, Ni	0
5984.810		0000	5998.002	Fe	2
5985.040 s	Fe	6	5998.442		000
5985.435	A (wv)	0	5998.760		0000
5985.615	A?	0000	5999.115		0000
5985.731	A?	0000	5999.204		000
5985.924	A?	0000 N	5999.436	A (wv)	00
5986.350		000	5999.647		0000 N
5986.674		0000	5999.920	Ti, A (wv)	0
5986.975		0000 N	6000.269		0000
5987.290 s	Fe	5	6000.370	A (wv)	00
5987.525		0000	6000.900	A?	00
5987.774		0000	6001.345	A?	000
5988.048	A?	0000 N d?	6001.765	A (wv)	000
5988.325	A (wv)	000	6002.375	A (wv)	000
5988.574	A?	0000	6002.870	A (wv)	00
5988.785	A (wv)	0	6002.970		0000 N
5988.985		000	6003.239 s	Fe	6
5989.180		0000	6003.538		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
6004.095	A (wv)	000 N	6020.232 } s		2
6004.603		0000 N	6020.401 }	Fe	4
6004.895	A (wv)	00	6020.610		0000
6005.098	A?	0000	6020.873		0000
6005.228		0000	6022.016 s	Mn	6
6005.586		0000	6022.440		0000
6005.770	Fe	1	6022.690		0000
6006.003		0000	6023.239		0000
6006.280	A?	000 N	6024.171		0000
6006.605	A?	00	6024.281 s	Fe	7
6007.080		0000	6024.459		0000
6007.255		0000	6025.425		0000
6007.540	Ni	1	6025.000	A?	00
6007.760		0000	6026.380	A?	0000
6007.935		000	6026.615	A?	0000
6008.186 s	Fe	4	6026.900	A?	0000
6008.450		0000	6027.040		0000
6008.556		0000	6027.274 s	Fe	4
6008.785 s	Fe	6	6027.485		0000
6009.031		0000	6027.650		0000
6009.580	A (wv)	000	6027.948	A,-	000 N
6010.066	A?	0000	6028.220	A	000
6011.001		0000 N	6028.490	A?	000 Nd?
6011.745		0000	6028.720		0000
6011.980		0000	6029.100		0000
6012.210		0000 N	6029.500		0000 N
6012.450	Ni	1	6030.110	A (wv),-	0
6012.660		000	6030.550		0000
6012.996		000 N	6030.860		0000 N
6013.416		000 N	6031.240		00 N
6013.715 s	Mn	6	6031.520		0000 N
6014.130		0000 N	6031.932		0000
6014.641		0000	6032.176		0000
6015.058		0000 N d?	6032.374		0000
6015.258		0000	6032.885		0000 N
6015.475		000	6033.530		0000
6015.830	A?	0000	6033.810		0000 N
6016.070	A?	000	6034.265	A?	0
6016.233		0000	6034.440		0000
6016.624		0000	6034.715		0000 N
6016.861 s	Mn	6	6035.137		0000 N
6017.140		0000	6035.575	A?	0
6017.080		0000	6036.121		0000 N
6018.524		0	6036.434		0000
6018.760		0000	6036.685	A?	0
6019.039	A?	0000	6037.009		0000
6019.372	A (wv)	000	6037.687		0000
6019.596	Ba?	000	6039.540		0000
6019.795		0000 N	6039.693		0000
6020.000		0000 N	6039.808		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
6039.953	V	0	6063.316		0000
6040.190		0000	6063.522		0000 N
6042.198		0000	6064.258		000 N
6042.315 s	Fe	3	6064.853	Ti	00
6042.480		0000	6065.709 s	Fe	7
6042.942		0000	6066.020		0000
6043.164		0000	6067.492		0000
6043.640		000	6067.850		000
6043.843		0000	6068.172		0000
6044.258		0000 N	6068.704		0000
6045.705		000	6069.931		0000
6045.985		0000	6070.303		0000
6046.245		0 N	6071.575		0000
6047.280	A?	0000 N	6071.970		0000
6047.880		0000	6072.238		0000
6048.495	A?	0000 N	6073.410		0000
6049.011	A?	0000 N	6073.772		0000
6049.337		000 N	6074.230		0000
6051.245		0000 N	6075.739		0000
6052.061		0000 N	6076.360		000 Nd?
6052.828		000	6076.820		0000 N
6052.906		00	6077.120		00
6053.153		0000 N	6077.480		0000 N
6053.233		0000 N	6077.702		0000 N
6053.476		0000 N	6078.060		000 N
6053.690		000	6078.410		0000 N
6053.912	Ni	0	6078.710 s	Fe	5
6054.125		0000	6078.978		000 N
6054.290	A?	00	6079.227 s	Fe	2
6055.310		000	6080.230		000
6055.620		000	6080.450		0000
6055.980		0000 N	6080.794		0000 N
6056.227 s	Fe	5	6081.422		0000 N
6056.565		000	6081.665	V	0
6056.987		0000 N	6081.930		0000
6057.110		0000	6082.050		0000
6057.475		00 N	6082.640	Co	000 Nd?
6058.080		0000	6082.930	Fe	1
6058.385		000 N d?	6083.915		0000 N
6058.874		0000	6084.325		0
6059.484		0000	6085.470	Ti, Fe	2
6059.970		0000	6085.656		0000
6060.340		0000	6086.128		0000
6060.853		0000	6086.500	Ni	1
6061.037		0000	6086.885		0000 N
6061.870		000	6088.047		00 N
6062.455		0000 N	6088.490		0000 N
6062.704		0000	6089.275		0000 N
6062.910		000	6089.538		0000
6063.080		0	6089.787	Fe	1

ON THE PERFORMANCE OF AN AUXILIARY LENS FOR SPECTROGRAPHIC INVESTIGATIONS WITH THE THIRTY-INCH REFRACTOR OF THE PULKOWA OBSERVATORY.

By A. BÉLOPOLSKY.

IN order to better adapt the thirty-inch refractor of the Pulkowa Observatory to spectrographic investigations, an auxiliary lens has recently been constructed, according to the plan proposed by Professor Keeler.[1] The lens has a diameter of 60^{mm}, and it is placed $1^{m}.070$ above the focus for the F line of the thirty-inch objective. According to Herr Steinheil, who made the lens, the radii of the surfaces are as follows:

$$\left.\begin{matrix} 421^{mm}.7 \\ 421\ \ .7 \end{matrix}\right\}\text{Flint} \qquad \left.\begin{matrix} 421\ \ .7 \\ 302\ \ .5 \end{matrix}\right\}\text{Crown}$$

The lenses are cemented together.

The lens is secured at a place where there was formerly a large prism, which reflected the light from the objective at right angles into a direct-vision spectroscope. By means of a pinion it can be moved axially in the cone of rays, and its position is indicated by a divided head. Screws are also provided for the necessary adjustments. Since at certain times in Pulkowa optical surfaces become heavily clouded with moisture, the lens is so mounted with a bayonet clip that it can be removed from the tube of the refractor for examination and replaced without disturbing the adjustments.

In order to estimate the advantages afforded by the lens, I made a series of spectrograms of α Persei and α Cassiopeiae, the slit-width and time of exposure remaining unchanged. It was found that the introduction of the lens shortened the focal length of the refractor for the $H\gamma$ rays by 10^{mm}, an amount which is well within the range of the collimator slide (60^{mm}). The length of the spectrum was considerably increased; without the lens the spectrum of α Persei extended from λ 441 to λ 423 (spectrograph No. 3), while with the lens it extended from λ 486 to λ 400. For α Cassiopeiae the lengths of the photographed spectra were as follows:

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[1] *Ap. J.* 1, 101, 1895.

Without lens, - - λ 438—λ 423
With lens, - - - λ 430—λ 410

Measurement of the width of the spectra gave the following results:

α PERSEI, COLLIMATOR 22.5.

With Lens			Without Lens		
λ	Measured Width	Reduced Width	λ	Measured Width	Reduced Width
4004	$0^{mm}.12$	$-0^{mm}.06$			
4045	0 .16	−0 .02			
4101	0 .18	0 .00			
4227	0 .29	+0 .11	4227	$0^{mm}.19$	$+0^{mm}.01$
4272	0 .32	+0 .14	4272	0 .27	+0 .09
4341	0 .33	+0 .15	4341	0 .40	+0 .22
4405	0 .36	+0 .18	4384	0 .56	+0 .38
455	0 .40	+0 .22	441	0 .67	+0 .49
467	0 .41	+0 .23			
482	0 .33	+0 .15			
486	0 .19	+0 .01			

Since the width depends partly upon the rate of the driving clock, all the above measures are reduced to a width of $0^{mm}.18$.

α CASSIOPEIAE, COLLIMATOR 27.0.

With Lens			Without Lens		
λ	Measured Width	Reduced Width	λ	Measured Width	Reduced Width
427	$0^{mm}.19$	$0^{mm}.00$	4227	$0^{mm}.20$	$0^{mm}.05$
433	0 .22	0 .03	4235	0 .15	0 .00
435	0 .25	0 .06	4261	0 .18	0 .03
445	0 .25	0 .06	428	0 .20	0 .05
455	0 .26	0 .07	431	0 .30	0 .07
460	0 .26	0 .07	434	0 .37	0 .22
465	0 .26	0 .07	438	0 .50	0 .35
470	0 .25	0 .06			
480	0 .23	0 .04			

(Reduced to a width of $0^{mm}.19$.)

For comparison I give the reduced widths of spectrograms obtained with the same spectrograph mounted on the large photographic telescope:

λ	Width
410	$0^{mm}.05$
420	0 .07
434	0 .06
441	0 .07
480	0 .03

The intensity of the spectrograms is fairly uniform throughout the whole spectrum, although in comparison with the intensity of a short interval (λ 423–λ 427) of a spectrogram which was taken without the lens, the latter is somewhat the greater. This circumstance may be caused in two ways: first, the (observed) rays may not be so accurately united in a point; second, the correcting lens may absorb part of the light.

A further advantage of the lens is that with it the star can be seen on the slit, a circumstance which greatly facilitates the task of guiding. No difference can be perceived between the spectral lines obtained with and without the lens.

PULKOWA, December 1895.

MINOR CONTRIBUTIONS AND NOTES.

MISS BRUCE'S GIFT TO THE ASTROPHYSICAL JOURNAL.

THE Editors take pleasure in announcing that Miss Catherine W. Bruce of New York has presented to the University of Chicago the sum of one thousand dollars, to be used for the purpose of providing illustrations for THE ASTROPHYSICAL JOURNAL. In view of the important part played by photography in astrophysical work at the present time, the possibility thus afforded of reproducing the best results of recent investigations may be expected to add materially to the valu of the JOURNAL. Miss Bruce's numerous benefactions to astronomy i both Europe and America have brought her the gratitude of many persons, among whom the Editors and readers of this JOURNAL may no be counted.

ON MR. F. W. VERY'S REMARKS CONCERNING MY NOTE ON LAWS OF RADIATION.

BEFORE entering upon a discussion of the experimental basis of Mr. Very's objections to the relations I have deduced from the observed energy spectra of iron oxide, I wish to point out that but one of the two relations arrived at can be called a principal of radiation, namely the law $\lambda_{max.} \times$ Abs. T. = Const. The other relation, $\lambda_1 \times \lambda_2 = \lambda^2_{max.}$ which, according to my observations, holds only in the vicinity of the maximum, can hardly be considered a general principle. As a matter of fact, I have regarded this relation only as a very useful means of determining from the values of λ_1 and λ_2 the exact position of the maximum. Determinations of the maximum made in this way are of great accuracy, for slight errors of the points of observation accumulated near the maximum are of much less effect in displacing its position than they would be if no similar relation existed.

Whether this relation and the other law proposed in my paper are accurate also for temperatures lower than 228° C. and higher than 1009° C. is a question whose probability I have discussed in my paper. For lower temperatures the form and the maximum of the normal

Very that this extrapolation transcends actual knowledge. But there can be no doubt that the determinations of the temperature of the Sun and the electric arc made by Messrs. Gray and Wilson also belong to this class of work, as they were made by a very large extrapolation of empirical laws which of course also transcends actual knowledge. Nevertheless Mr. Very takes from them the temperature of the electric arc for the curve of the positive carbon, which is his second instance of deviation from my law.

From the data published by Langley[1] it is impossible to calculate either the position of the maximum or the form of the curve in its neighborhood with any accuracy, as but two points are given near enough to the maximum of the normal curve. A small error in these determinations would displace the maximum to a very considerable extent. These two points are 40° 5′ (angle of prism 60°), or $0^{\mu}.933$, and 39° 54′, or $1^{\mu}.067$, with the respective heights 207 and 211 reduced to the normal scale. The next points on both sides are too far away to be used in the determination of the maximum. Assuming these two points to be correct, and their ordinates to be of equal height within the limits of error, $\lambda_{\text{max.}}$ would be $\sqrt{1.067 \times 0.933} = 0^{\mu}.998$. According to my relation this would give for the carbon a temperature of $\frac{2727}{0.998} = 2729°$ abs. This would represent a lower limit for that temperature, because in my observations $\lambda_{\text{max.}} \times$ Abs. T. increases a little with the temperature, and therefore 2727, the highest value observed for 1009° C., might still be a little too low. Further, it seems to me very difficult to screen off all the light except that from the small point of greatest brilliancy in the arc. If light from the cooler parts of the arc also falls upon the bolometer, the greater wave-lengths would have ordinates relatively too great, and the maximum would suffer a corresponding displacement. This might also be a cause of lowering the temperature calculated in this way. The calculated temperature of the positive carbon of the arc does not seem to be an improbable one. But the published data are too few and seem too incomplete to warrant any conclusions. Langley himself says of this curve: "The observations were not repeated to obtain such a thorough comparison as would be desirable . . . we will give them here under the caution that they are to be considered only first approximations." If Mr. Very has used nothing but these observations (the only ones which he quotes in his note) I do not believe that his objections are well founded. Neither the determination of the temperature nor the observation of the maximum of the curve would to any considerable degree be comparable in accuracy with my observations.

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[1] S. P. LANGLEY, *Am. Jour. Sci.* (3), **38**, 1889, p. 438.

F. PASCHEN.

TEST OF THE FORTY-INCH OBJECTIVE OF THE YERKES OBSERVATORY.

IN September, 1895, Mr. Alvan G. Clark reported that the forty-inch object glass of the Yerkes Observatory was completed. By the terms of the contract it was necessary to have the objective examined by an "expert agent" before its acceptance by the Observatory, and on account of my familiarity with the Lick telescope, I was invited by Professor Hale to accompany him to Boston, and test the lens in the capacity above mentioned.

Our examination was made on the nights of October 17, 18, 19 and 21, 1895. The temporary equatorial mounting for the lens stands in the open air near Mr. Clark's factory in Cambridgeport; it is the same mounting which was used for testing the Princeton, Washington and Lick objectives, the masonry pier having been twice built higher to accommodate the progressively increasing length of tube required for these different telescopes. There is no clockwork, and the observer has to follow a star by pressing on two handles which project from the lower end of the tube; usually he is aided by an assistant. The motion in right ascension is as smooth as could be expected, but it is not a perfectly easy matter to keep an equatorial star in the center of the field with a high power.

The construction of the objective is quite similar to that of the Lick telescope, the lenses being separated by a space of about seven inches. Both lenses are remarkably free from air-bubbles, "stones" and striæ. Their weight, with that of the cast-iron cell in which they are mounted, is one thousand pounds.

Under the atmospheric conditions which generally prevail at Boston, it is quite impossible to test so large an objective as the forty-inch with the definite results that can be obtained in the case of a smaller aperture or a steadier atmosphere. It is necessary to make large allowances for atmospheric disturbance. Mr. Clark informs me that at his factory he has never seen diffraction rings around a star disk, although they are easily seen with the Lick telescope in its present situation. Hence it was extremely difficult to estimate what the undisturbed distribution of light in the image at the focus would be, and it was useless to attempt the observation of close double stars near the theoretical limit of resolution, since this is merely another method of estimating the diameter of the central disk of the diffraction pattern. With a knife-edge at the focus (Foucault's test), the objective appeared to be filled with tremulous patches of light, constantly changing their position, but on the whole representing a distribution of light which seemed to be uniform. The most satisfactory test that could be made under the actual conditions was to examine the cross-section of the cone of rays at different oints inside and outside of the focus, and for this purpose the makers ad provided a long draw-tube, sliding by hand with a very smooth nd easy motion.

On the first night a slight elongation of the expanded star disk led to experiment on the effect of changing the relative positions of the nses. It was found that when the great tube was pointed to the nadir, number of men, by pressing upward on the crown lens so as to relieve e supports of its weight, could turn the lens without removing it om the cell; thus the experiments were made without much trouble labor. In certain positions of the crown lens the elongation of the age became quite pronounced, and in no position was it less than at st. Finally, on October 21, the lens was restored to its original sition, and then both lenses were turned 90°, the operation in this se requiring their removal from the cell. In the evening the sky as very clear and the definition exceptionally good;—perhaps nearly good as it ever is at the place where the telescope was mounted. he last change in the lens had also been an improvement. The panded star disk was round inside and outside of the focus, uniformly uminated, and free from wings or other appendages. Good images the focus were obtained of stars at widely different altitudes near the eridian, the definition being in my opinion, with due allowance for mospheric disturbance, equal to that of the Lick telescope, while the ightness of the image was of course considerably greater than with e latter instrument. With a low power the nebula of Orion was a onderful object, and the bluish green color in the Huyghenian region as more vivid than I have ever seen it in an extended nebula. The inute stars in the trapezium discovered with the Lick telescope were robably, though not certainly seen, the imperfections of the mounting interfering greatly with this class of observations. Sirius was examined when it was at a considerable distance east of the meridian, and an unsuccessful search was made for the companion. The absence of ghosts and the small amount of diffuse light when this brilliant star was in the field were particularly noted. The color correction of the forty-inch objective is, according to my best recollection, almost precisely the same as that of the Lick objective.

From these tests it appears that the character of the image varies with the position of the lenses relatively to each other, and, to a less extent, with the position of the objective as a whole relatively to its cell. It is probable that flexure of the lenses is the principal cause of the observed changes, and it is interesting to note that there is here evidence, for the first time, that we are approaching the limit of size in the construction of great objectives. A more complete investigation of the subject can be made only after the objective is permanently mounted, so that stars can be observed at widely different hour angles. The flexure seems to be of the kind frequently noted in the construction of large mirrors, which are found to give the best definition when a certai diameter is placed vertical. It is not likely that the effects of flexur will be appreciable in the case of the forty-inch objective when the lense are properly adjusted; for larger objectives, it is possible that the lim above referred to may be extended by providing their cells with position circle, so that they can be rotated about the axis of the telescope tube.

All the tests described above were made jointly by Professor Ha and myself, and the conclusions at which we arrived are substantial the same.

JAMES E. KEELER.

NOTE ON THE APPLICATION OF MESSRS. JEWELL, HU PHREYS AND MOHLER'S RESULTS TO CERTA PROBLEMS OF ASTROPHYSICS.

THE fact that the wave-length of a spectral line is a function of pressure of the gas or vapor producing it, is obviously of prime imp ance in astrophysics. In spite of certain well-established phenom such as the unsymmetrical reversal of metallic lines in the arc and interesting observations by Ebert of a change in the position of a l when the amount of material in a flame is varied, the Fraunhofer li have been regarded as fixed marks of reference, subject to no poss change in position. Moreover, but little evidence has been advanced to show that any of the Fraunhofer lines vary in intensity, though that a secular change is going on is indicated by the variety in type of stellar spectra. Some remarkably fine photographs of the *b* group in the solar spectrum, made by the Rev. Walter Sidgreaves in 1891 with a Rowland plane grating of 14,438 lines to the inch, seemed to show that the line No. 17 of Professor Winlock's maps in the *Proceedings of the American Academy* had decreased in intensity.[1] Professor Hastings' observations in 1873 of the different intensities of certain lines at the center of the solar disk and near the limb may also be mentioned in this connection.[2] Ångström had previously pointed out some apparent variations of a more general character.[3] It seems, however, to have remained for Mr. Jewell to establish with certainty a variation in the intensity of an absorption line in the general spectrum of the Sun. Every photograph of the solar spectrum taken with high dispersion must now be regarded as a document of great value, which may ultimately reveal irregular or periodic changes in the condition of the gases and vapors of the solar atmosphere.

The double reversal of the H and K lines was discovered almost simultaneously by M. Deslandres and myself in 1891. In the following year I pointed out the lack of symmetry in the reversals,[4] without offering an explanation of this peculiarity. In the same year M. Deslandres[5] and the Rev. Sidgreaves found the double reversals in the spectrum of general sunlight, and showed that the Sun might therefore be classed as a bright line star. M. Deslandres has recently investigated the displacement of the central absorption line of the double reversal, and ascribes it to motion of the absorbing gas.[6]

It now appears that all of these observations were anticipated by Mr. Jewell, who discovered the double reversals in the general spectrum and in various parts of the solar disk in 1889. He detected the displacement of the central line, and somewhat later attributed it to motion in the line of sight.

In connection with Mr. Jewell's paper it will be of interest to consider some of the results arrived at by M. Deslandres in the article already referred to. After remarking that the dark absorption line is usually central over faculæ, M. Deslandres adds: "En dehor des facu-

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[1] *A. and A.* 11, 79, 1892.

[2] *Nat.* 8, 77, 1873.

[3] *C. R.* 63, 648, 1866.

[4] *A. and A.* 11, 813, 1892.

[5] *C. R.* 1892.

[6] *C. R.* 119, 457.

les, par contre, la dissymétrie des composantes brillantes, qui, d'ailleurs, sont faibles, est le cas le plus fréquent; elle est nette, en général, au moins sur les trois quarts de la surface, dans le sens de la lumière générale, et est plus ou moins accentuée, étant quelquefois telle que la composante rouge est invisible. Elle se présente aussi bien près de l'équateur que près des pôles, mais très rarement à une faible distance du bord."

My own photographs seem to show that the disappearance of the red component of the emission line is not always due to the displacement of the central absorption line, but usually simply results from the fact that this component is less brilliant than the more refrangible one. Mr. Jewell's curve (Fig. 7, p. 100) closely represents the distribution of light in the doubly-reversed line.

Mr. Jewell and M. Deslandres consider that the displacement of the central line is due to motion of the absorbing gas. In M. Deslandres' words, "L'ensemble des faits précédents peut s'expliquer par un mouvement général de circulation verticale et horizontale des couches hautes et basses de la chromosphère, analogue à celui que présente notre atmosphère. Les couches basses s'élèveraient et seraient attirées vers l'équateur, comme les vents alizés, d'où un rapprochement vers la Terre; les couches élevées auraient un mouvement inverse." M. Deslandres endeavored to determine the absolute displacement of the central dark absorption line at the center of the disk and the corresponding emission line in the chromosphere at the limb by comparing them with lines in the spark spectrum of iron. He found an apparent slight shift of certain parts of the absorption line toward the red, with respect to the iron lines, while the emission line of the chromosphere "présentait un déplacement moindre ou inverse." M. Deslandres concludes that the dispersion employed (4th order of a Rowland grating, with observing telescope of $1^m.30$ focus) was insufficient for the purpose. It was noticed, however, that "les composantes brillantes de la raie du calcium dans l'étincelle présentent aussi une légère dissymétrie dans le même sens que la raie solaire," and it is suggested that these similar displacements may be due to similar causes.[1]

We now know that the reversed line in the spark spectrum should be unsymmetrical, if the pressure conditions in the arc and spark are similar. The emission line, produced by the radiation of the vapors in the central part of the spark, should be displaced — not, as M. Deslandres' words would seem to indicate, toward the violet, but toward the red. The central line of absorption would thus appear to be displaced toward the violet with respect to the emission line, an appearance exactly the reverse of that existing in the spectrum of the solar surface. It therefore seems to be impossible to account for the lack of symmetry of the H and K reversals in the Sun by ascribing it to the different pressures of the upper and lower strata of the chromosphere. That such a difference exists is indicated by the broadening of the lines at the lower level. There is therefore in all probability a displacement of the emission lines toward the red, due to this cause, but it is partly or wholly overcome by a displacement in the opposite direction, due apparently to motion in the line of sight.

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[1] *C. R.* 119, 459, 1894.

But even this latter explanation is not free from difficulties. M. Deslandres' suggestion that the vapors in the lower stratum of the chromosphere have an ascending motion, and are drawn toward the equator, while the vapors of the upper stratum move inversely, would seem to apply perfectly, were it not for the fact that the displacement of the central absorption line, according to his observations, is well defined over at least three-quarters of the surface, and is as commonly present near the equator as near the poles, though rarely at a slight distance from the limb. In other words, the vapor which produces the central absorption line, on whatever part of the surface it may be found (except near the limb) is moving away from the observer. In the absence of further information, there would seem to be as much evidence of descending vapor flowing east and west from the central meridian (which is manifestly out of the question), as there is of descending vapor flowing north and south from the equator. Many solar theories have postulated such a current, but hitherto its existence has not been certainly established. It will be a matter of extreme interest to investigate this question further. I very much regret that the numerous photographs of the H and K reversals on the Sun's surface made at the Kenwood Observatory during the last five years have been taken with a dispersion insufficient to permit of their use in a case of this kind. The solar spectroscope now in process of construction for the forty-inch Yerkes telescope will, it is hoped, be sufficiently powerful for the purpose.

The difference in behavior of H and K and the blue line of calcium discovered by Messrs. Jewell, Humphreys and Mohler seems to support Lockyer's views as to the dissociation of calcium in the arc and Sun. The remarkable variations of the calcium spectrum with temperature have long been known, principally through the investigations of Lockyer. The writer has shown that the H and K lines are produced at the temperature of burning magnesium and in the oxy-coal-gas flame. They could not be photographed in the spectrum of the Bunsen burner, though an exposure of sixty-four hours was given. Since these experiments were made I have been informed by Professor Eder that his own efforts to photograph the lines in the Bunsen burner were no more successful, though an optical train of quartz and fluorspar was employed. It would thus appear that the temperature of dissociation of calcium is between that of the Bunsen burner and that of the oxy-coal-gas flame. The high molecular weight of calcium has hitherto conflicted with our belief in the presence of this metal in prominences. If, however, it be granted that dissociation can be brought about by temperatures even lower than that of the arc, the difficulty is very greatly lessened.

Although it has been shown that the range of pressure in the reversing layer is considerable, it would probably be premature to argue that its depth must therefore be comparable with that of the corona. There seems as yet to be no certain evidence that any absorption line in the solar spectrum has its origin above the upper limits of the chromosphere. Mr. Jewell suggests that the central dark line of the H and K reversals is produced by the corona. In this case it should show a very decided relative shift toward the violet, due to the different pressures of the chromosphere and corona, and be subjec to relative displacements near the east and west limbs of the Sun toward the violet and red respectively, due to the difference between the components in the line of sight of the velocities of rotation o the chromosphere and corona. These displacements would be complicated with those resulting from internal motions of the coronal vapors but a careful study of the H and K reversals in various parts of th solar surface, made with very high dispersion, would probably decid the question. However, the close similarity of the central absorption line on the disk and the emission line in the upper part of the chromosphere at the limb, seems to make unnecessary the assumption tha the corona plays any part in the absorption. In this connection i would be interesting to determine whether the distance between the components of the 1474 line is constant over the entire surface of the Sun

The problem of the solar rotation, so admirably investigated by

Crew and Dunér, gains new interest in the light of present knowledge. It is now possible to determine whether the lines employed in these two researches originate in different parts of the reversing layer, in which case it might become possible to harmonize the results. It can hardly be said that the ideas of Brester[1] on this point are sufficiently plausible to gain general acceptance.

It is impossible in a limited space to even touch upon the numerous applications of the new results to astrophysical problems. That the effect of pressure must receive attention in future investigations of the motions of stars and nebulæ in the line of sight cannot be doubted. The fact that narrow spectral lines are not always inconsistent with high pressures is of great importance in this connection. The close similarity of stellar spectra of Class II*a* with the solar spectrum indicates that the conditions of temperature and pressure in the atmospheres of these stars cannot differ widely from those existing in the Sun. The displacements due to pressure must therefore in such cases be in general too small to be detected with an ordinary spectrograph, and the measures of motion in the line of sight may be relied upon. In stars whose reversing layers are subject to higher pressures the displacements due to this cause may become appreciable. Fortunately, however, it has been shown that the wave-lengths of certain lines in the spectrum are apparently unaffected by pressure. These lines, if they can be found in the stars under investigation, may serve for the determination of motion in the line of sight. The pressures in the reversing layer might also be measured with other lines. It is evident, as Mr. Jewell has pointed out, that the vacuum tube should replace the spark or arc for this work. The form used by Professor Michelson, and described in a recent number of this JOURNAL,[2] is probably the best for the purpose.

GEORGE E. HALE.

ON THE SPECTRUM OF CLÈVEITE GAS.

THROUGH a mistake in the types, it was made to appear that Professors Runge and Paschen's article in the last number of this JOURNAL had been published elsewhere. This, however, was not the case. The foot-note on page 4 was intended to refer to previous papers by the same authors.

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[1] *Théorie du Soleil.*

[2] *Ap. J.* 2, 263, 1895.

HARVARD COLLEGE OBSERVATORY. CIRCULAR NO. 4.

A NEW STAR IN CENTAURUS.

A NEW star in the constellation Centaurus was found by Mrs. Fleming on December 12, 1895, from an examination of the Draper Memorial photographs. Its approximate position for 1900 is in R. A. 13^h $34^m.3$, Dec.—31° 8′. Attention was called to it from the peculiarity of the spectrum on Plate B 14151, taken at Arequipa on July 18, 1895, with the Bache Telescope, exposure 52^m. The spectrum resembles that of the nebula surrounding 30 Doradus, and also that of the star *A. G. C.* 20937, and is unlike that of an ordinary nebula or of the new stars in Auriga, Norma and Carina. This object is very near the nebula *N. G. C.* 5253, which it follows $1^s.28$, and is north 23″. No trace of it can be found on 55 plates taken from May 21, 1889, to June 14, 1895, inclusive. On July 8, 1895, it appeared on a chart plate, B 13965, and its magnitude was 7.2. On Plate B 10472 taken July 10, 1895, its magnitude was also 7.2. On December 16, 1895, a faint photographic image of it, magnitude 10.9, was obtained with the 11-inch Draper telescope, although it was very low, faint and near the Sun. On this date, and on December 19, it was also seen by Mr. O. C. Wendell with the 15-inch equatorial as a star of about the eleventh magnitude. An examination with a prism showed that the spectrum was monochromatic, and closely resembled that of the adjacent nebula. Although the spectrum is unlike those of the new stars in Auriga, Norma and Carina, yet this object is like them in other respects. All were very faint or invisible for several years preceding their first known appearance. They suddenly attained their full brightness and soon began to fade. Like the new stars in Cygnus, Auriga and Norma, this star appears to have changed into a gaseous nebula.

The star which was photographed in 1887 in the constellation Perseus apparently belongs to the same class. Its approximate position for 1900 was in R. A. 1^h $55^m.1$, Dec. + 56° 15′. Eight images of it were obtained on the Draper Memorial photographs in 1887, all in exactly the same place. Its photographic spectrum showed the hydrogen lines $H\beta$, $H\gamma$, $H\epsilon$, and a line near 4060, bright, and from this property it was discovered by Mrs. Fleming and assumed to be an ordinary variable star of long period. The spectrum is so faint that it is impossible to decide from it whether it should be regarded as a new star of the class of Nova Aurigae, or as a variable star of long period like o Ceti, as the hydrogen lines are bright in both these classes of objects.

The star soon faded away and does not appear on 81 photographs taken during the last eight years. It has also been repeatedly looked for in the sky without success. No trace of this star appears on two photographs taken November 3, 1885, and December 21, 1886.

A list of the new stars hitherto discovered is given in the annexed table. Some changes would occur in it, if changes were made in the definition assumed for this class of objects. Early observations of several objects frequently called new stars, but which may have been comets, and whose positions are uncertain, have not been included. The stars T Bootis and U Scorpii have not been included, although they also may be new stars, as only one appearance of each has been noted. The name of the constellation is followed by the right ascension and declination for 1900, and the greatest brightness. The year of appearance is followed by the name of the discoverer; or, in the case of the earlier stars, of the principal observer.

NEW STARS.

CONSTELLATION	R. A. 1900	DEC. 1900	MAG.	YEAR	DISCOVERER
	h m	° ′			
Cassiopeia	0 19.2	+63 36	−5?	1572	Tycho Brahé
Cygnus	20 14.1	+37 43	3	1600	Janson
Ophiuchus	17 24.6	−21 24	−4?	1604	Kepler
Vulpecula	19 43.5	+27 4	3	1670	Anthelm
Ophiuchus	16 53.9	−12 44	5	1848	Hind
Scorpius	16 11.1	−22 44	7	1860	Auwers
Corona Borealis	15 55.3	+26 12	2	1866	Birmingham
Cygnus	21 37.8	+42 23	3	1876	Schmidt
Andromeda	0 37.2	+40 43	7	1885	Hartwig
Perseus	1 55.1	+56 15	9	1887	Fleming
Auriga	5 25.6	+30 22	4	1891	Anderson
Norma	15 22.2	−50 14	7	1893	Fleming
Carina	11 3.9	−61 24	8	1895	Fleming
Centaurus	13 34.3	−31 8	7	1895	Fleming

THE NEW ALGOL VARIABLE IN DELPHINUS.

The variable star of the Algol type, *B. D.*+17° 4367, in the constellation Delphinus, announced in Circular No. 3, was again found to be faint by Professor Searle on December 17, 1895. From a discussion of the photographic and visual measurements so far made, it appears that its period is about $4^d\ 19^h\ 21^m.2$, and that it will again become fainter than the eleventh magnitude from $11^h.6$ to $15^h.8$, Greenwich Mean Time, on January 5, 1896.

EDWARD C. PICKERING..

December 20, 1895.

RECENT PUBLICATIONS.

A LIST of the titles of recent publications on astrophysical and allied subjects will be printed in each number of THE ASTROPHYSICAL JOURNAL. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors.

For convenience of reference, the titles are classified in thirteen sections.

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THE
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AND ASTRONOMICAL PHYSICS

VOLUME III MARCH 1896 NUMBER 3

THE MODERN SPECTROSCOPE. XVI.

A SIMPLE OPTICAL DEVICE FOR COMPLETELY ISOLATING OR CUTTING OUT ANY DESIRED PORTION OF THE DIFFRACTION SPECTRUM, AND SOME FURTHER NOTES ON ASTRONOMICAL SPECTROSCOPES.

By F. L. O. WADSWORTH.

THE overlapping spectra always produced by a diffraction spectroscope, while exceedingly useful and convenient in the determination of relative wave-lengths, are on the other hand very disadvantageous in photographic and bolometric investigation of the spectrum, particularly in the red and the infra-red regions. In order to isolate any desired portion of the spectrum of a given order, or to avoid the disturbing effect of the overlapping spectra in the classes of work just referred to, it is customary to either use absorbing screens, so chosen as to cut out as completely as possible those portions of the spectrum which are superposed on the part under examination; or to use what is known as the "lifting" prism, first proposed by Fraunhofer, and since used by Professors Young, Langley and others, by the action of which the different orders of spectra are displaced vertically by different amounts.

Of these two methods the first is the more simple and direct, and since the absorbing media may be placed in front of the slit, the definition of the instrument is not affected by optical imperfections in the surfaces or material of the absorbing film or cell. The great practical disadvantage of this method is that there are no materials known which are perfectly transparent to some one portion of the spectrum and perfectly or even nearly opaque to other regions, and much time is frequently lost in trying to find solutions which will most nearly secure the selective absorption required. Professor Ames has published[1] a list of absorbing solutions which answer very well for particular regions of the visible spectrum, but none of these are well adapted to the extreme infra-red region, and all of them diminish to a greater or less degree the intensity of those rays which they are intended to transmit, both by partial absorption and by reflection at the surfaces of the cell or film.

The second method of separating the spectra of different orders by the use of Fraunhofer's "lifting" prism placed between the grating and the eyepiece, completely accomplishes the object desired, *i. e.*, a complete separation of the different orders of spectra, and enables any portion of any order to be isolated or cut out at will by means of sliding screens placed just in front of the eyepiece or photographic plate. But this method has also obvious disadvantages due to the introduction of a prism in the spectroscope train. Owing to the position of this prism (refracting edge at right angles to the lines on the grating) the rigidity of the observing telescope is seriously affected; not only by its being brought into an unusual, and in many respects an inconvenient position, but also by the necessity for making it movable in a vertical plane in order to bring different portions of the spectrum into the center of the field.[2] This difficulty might be avoided by using the "direct vision fixed arm" prism train

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[1] "The Concave Grating in Theory and Practice." *Phil. Mag.* 27, 369.

[2] This last object may, it is true, be accomplished by rotating the prism alone on an axis parallel to its refracting edge, but only at the sacrifice of definition and brightness of the spectrum, since the diffracted rays then no longer pass through the prism at minimum deviation, except in one particular position.

PLATE XIV.

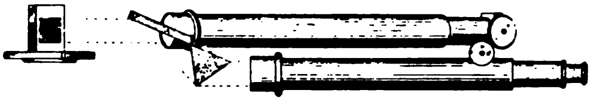

Fig. 1

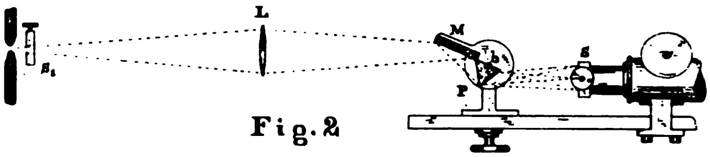

Fig. 2

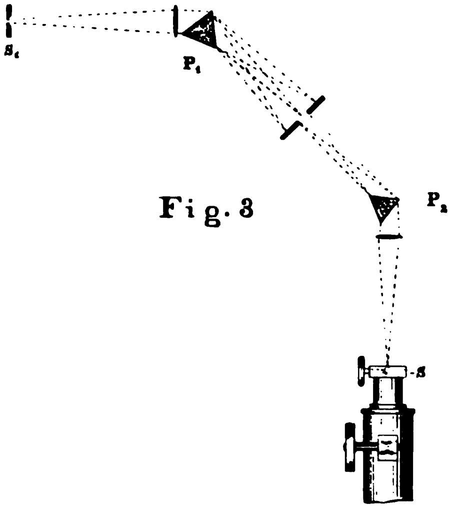

Fig. 3

described in a preceding paper.[1] The arrangement of parts then becomes the same as an ordinary plane grating spectroscope with fixed collimator and observing telescope, save that the latter is raised (or lowered) a distance equal to twice the distance of the axis of rotation of the prism from the horizontal plane passing through the axis of collimation (see Fig. 1, Plate XIV.). If the observing telescope were large enough even this small vertical displacement would be unnecessary, and exactly the same disposition of parts could be used with the prism or without.

A second disadvantage attending the use of the lifting prism which cannot be so easily and satisfactorily overcome, is that when it is used the spectra no longer cross the field at right angles to the spectrum lines, but are curved upward from the red end, the curvature becoming very great in the violet regions. This does not introduce any particular difficulty in the case of visual observations, but in photographic work it is very objectionable, especially when the spectrum is very narrow, because it renders the subsequent measurement and comparison of the lines on the dividing engine or comparator troublesome and more or less inaccurate.

In order to avoid injuring the definition the prism must of course be placed in front of the objective of the observing telescope. This is another disadvantage, for in order to completely utilize the full aperture of the grating we must have a prism with an aperture at least as large, and this for large instruments would not only be very expensive, but also very objectionable on account of the great absorption. Besides, the necessity for placing the prism, if used at all, in a parallel beam of light renders it quite impossible to use this arrangement with satisfactory results in the case of the concave grating.[2]

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[1] "Fixed Arm Spectroscopes." *Phil. Mag.* **38**, 337, 1894.

[2] Three years ago at Professor Langley's request I made experiments on the use of a prism placed between a concave grating and its focal plane, the apparatus being arranged with special reference to the bolometric investigation of the grating spectrum.

The arrangement, which is referred to in the Smithsonian report for 1893, consisted

Recently, in reconsidering this problem with special reference to some proposed work with the concave grating, two new methods suggested themselves, both of which have been tried with success and found to be not only free from the objections to the methods just discussed, but to offer in addition certain advantages not possessed by either. In both a prism is used, but unlike Fraunhofer's arrangement this prism is placed outside the slit of the spectroscope, and can therefore be used equally well with either a plane or a concave grating, and is in both cases without effect on the definition of the instrument. In the first method the prism is placed with its refracting edge at right angles to the slit of the spectroscope and between the latter and the usual condensing lens, as in Fig. 2, and a second broad slit, s_1, whose length is parallel to the refracting edge of the prism (and therefore at right angles to the spectroscope slit itself), is placed just in front of the source.[1] The image of the first slit or opening, s_1, is thus drawn out into a spectrum whose length is parallel to the spectroscope slit, and every point of the latter is thus illuminated with light of a different wave-length. Hence the resulting spectral image of this slit will be a band inclined across the field just as in Fraunhofer's arrangement, the width of this band being determined by the width of the first slit, s_1, and the ratio of the conjugate foci of the condensing lens, L; and its inclination in the field being determined by the angular dispersion of the prism, P, and its distance from the spectroscope slit. Both the width and inclination of the diffraction spectrum may therefore be readily varied, the first by

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of a large Rowland concave grating mounted in the usual manner with a direct vision prism mirror combination similar to that shown in Fig. 1, placed about two feet in front of the bolometer (which occupied the place of the usual observing eyepiece) and so mounted that as the bolometer strip moved down through the spectrum, the prism was, by means of a simple link and cam movement, automatically maintained in minimum deviation.

It was found that in spite of the most careful adjustment the definition was so much injured that the use of the prism in this way was impracticable except for the very roughest work.

[1] To avoid a change in the direction of the refracted rays we use in this case as before a direct vision prism mirror combination instead of the prism alone.

varying the width of s_1, the second by sliding the combination *PM* toward and from the slit *s*. In this case the diffraction spectrum may also be readily limited to any desired range of wave-lengths by limiting the vertical height of the spectroscope slit by stops, different portions of the spectrum being brought in succession into the field by rotating the prism and mirror, *PM*, on its horizontal axis, *b*. The distorting effect of the prism on the homocentric cone of rays from *L* is evidently without effect on the definition of the spectroscope itself, its only effect being to broaden and render indistinct the edges of the spectrum, an effect of the same nature as that produced by astigmatism in a concave grating.

This simple and efficient device has but one disadvantage: *i. e.*, the inclination of the spectra in the field of the observing telescope. The second method alluded to above overcomes also this disadvantage, although the arrangement of parts is not quite so simple as in the case just discussed.

If we turn the prism, *P*, and the first opening, s_1, 90° from the position which they occupy in Fig. 2, and allow the resulting prismatic spectrum to fall upon the spectroscope slit, *s*, we obtain what is in principle identical with the arrangement recently described by Tutton[1] as a new instrument for producing monochromatic light of any desired wave-length, and which had previously been used by Langley, Rubens, and others for the determination of wave-lengths in the prismatic spectrum. With such an arrangement the diffraction spectrum would be limited to a narrow band whose position could be changed by turning the prism on its axis, but whose breadth (in the direction of the length of the spectrum) could only extend over a few wave-lengths, and could not therefore be used when it is desired to photograph or examine a considerable portion of the spectrum at once. But if, instead of allowing the spectrum formed by the first prism to fall on the spectroscope slit, we project it on a screen in which there is a rectangular opening whose length can be varied, and place behind this opening a lens and a second prism of the same refracting angle and dispersion as the first, in such position that the rays which pass through the opening will be reunited by the second prism and lens into a chromatic image of the first slit; and then project this chromatic image on the spectroscope slit, we shall obtain a diffraction spectrum which will be limited to those wave-lengths that have been allowed to pass through the opening in the first screen. This arrangement, which was the one first used, is shown in plan view in Fig. 3, which will be readily understood from the preceding description.

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[1] *Phil. Trans.* 185, 913, 1895.

This arrangement soon proved, however, to be too bulky and difficult of adjustment for convenient use, and it was, moreover, difficult to obtain good chromatic images of s_1 at s, owing to slight differences between the two prisms P_1 and P_2. These difficulties were all overcome and the instrument got in very compact and convenient form by use of the Littrow principle of sending back the spectral rays on their own path by means of a double reflection prism R placed behind the screen D at the focal plane, with its hypothenuse surface perpendicular to the plane of refraction so that the chromatic image of s_1 fell just above or just below s_1 itself (see Fig. 4, Plate XV.). In this case the electric arc which serves as the source of light, instead of being placed directly against the first slit s, is on account of the proximity of this slit to the spectroscope, placed at some distance, and the image of the arc thrown on the slit s_1, by means of a condensing lens L'. The portion and the extent of the spectrum in the field can then both be readily varied, the first by moving the arm carrying the screen D and the reflecting prism R, and the second by varying the width of the opening in the screen at D.

This simple arrangement, which may perhaps be called an optical sifting screen, or sorting train, thus takes the place of an infinite number and variety of absorption screens or films. Since the lens L and prism P may be very small, they may always be made of materials which have a minimum absorption for the region under examination, quartz for the ultra-violet, white crown and flint glass for the visible, and rock salt or fluorite for the infra-red.

PLATE XV.

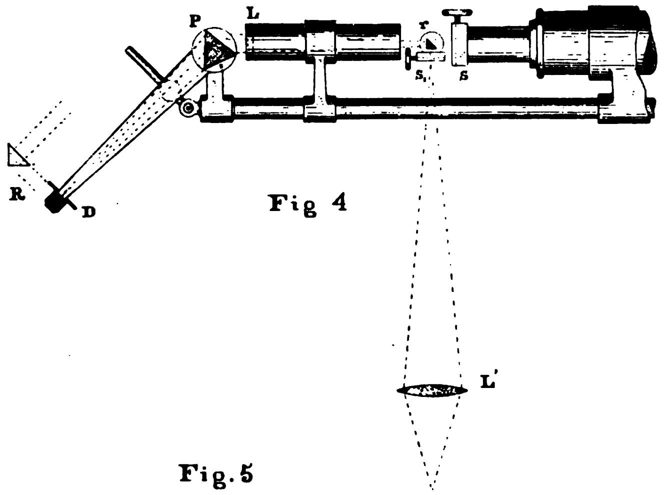


Fig 4

Fig. 5

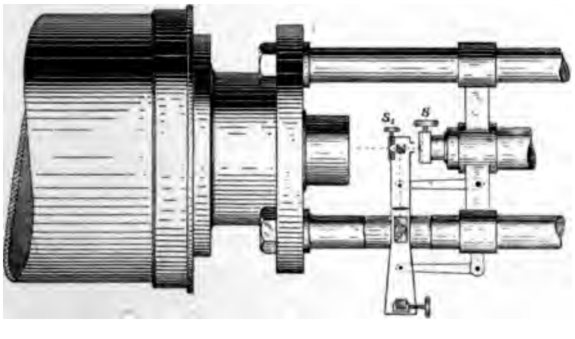
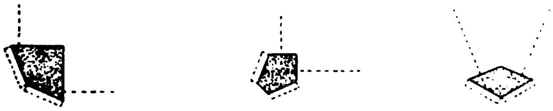


Fig. 6



The slit s_1 is so mounted that it can be readily moved to one side, and the right angled prism *r*, which is placed just behind it, revolved through 90° so as to throw the image of the source directly upon the spectroscope slit. Among other things, this enables us to readily compare the brightness of the spectrum with and without the sifting train, and such comparisons show that by the use of the latter the brightness is diminished by not more than 20 to 30 per cent., or to about the same degree as by the use of absorbing screens. Even were the loss considerably greater, however, it would be more than offset by the greater convenience, range of control and perfect screening action of this sifting train.

The compactness and small size of the whole arrangement enables it to be readily mounted on the end of the collimating telescope or on an extension of the arm which carries it, as in Fig. 4. By slightly modifying the arrangement of parts the train may readily be introduced in front of the slit of an astronomical spectroscope, as shown in Fig. 5. In this case the axis of the train is at right angles to the axis of collimation, and a direct vision prism is used in place of the single prism in order both to make the arrangement more compact, and to secure good definition in the second slit image with the use of but one lens in the train. Instead of a direct vision prism we might also use a Christie half prism, since no great degree of resolving power is here required.

The tube containing the lens, prisms, etc., is so mounted that it may be readily moved to one side, allowing the image of the source to fall directly on the spectroscope slit *s*, which is then moved out until it occupies the place of s_1.

One property of this train, which makes it valuable for certain problems in the determination of wave-lengths, is the possibility of producing artificial bands or lines of any degree of blackness, in any part of the spectrum. To do this it is only necessary to stretch wires of the desired thickness across the screen *D*, which will cut off from the image which falls on the spectroscope slit all those radiations which fall upon the wires at

D, and produce consequently lines at the corresponding points in the diffraction spectrum. By using wires or strips of materials which are more or less transparent we can produce any desired degree of absorption or shading off of intensity in different parts of the spectrum, while by using metal wires which are opaque to radiations of all wave-lengths we can produce lines or bands which are absolutely black at least at the center.

One important application of these artificially produced lines in the diffraction spectrum is the determination of wave-lengths in the prismatic spectrum. The wire which crosses the prismatic spectrum may in this case be the vertical cross-wire of the eyepiece of the observing telescope, by means of which its angular position in the prismatic spectrum may be more easily and accurately determined than the position of a slit can be, and the position of the sharp absorption line in the grating spectrum can also be more easily and accurately fixed by means of the bolometer than in the usual arrangement, in which we have a more or less diffuse bright line on a dark background.

SPECTROSCOPIC NOTES.—*Relative Advantages of Large and Small Spectroscopes.*—In my article "General Considerations Respecting the Design of Astronomical Spectroscopes," which appeared in the first number of THE ASTROPHYSICAL JOURNAL,[1] certain general conclusions were reached in regard to the general design of the compound spectroscope (the objective spectroscope was not considered), which have been criticised by a number of astrophysicists, Professor Keeler among others. Professor Keeler's criticisms are contained in a note to the last March number of THE ASTROPHYSICAL JOURNAL, and as they are the most extensive and detailed of any that have been made, it is these that I will especially consider. I may first remark that my answer to these and others has been so long delayed for the reason that I first wished to finish the present series of papers dealing with the design of different forms of astronomical spectroscopes in order that some of the points in the first paper might be more fully developed, and the conclusions there reached by theoretical considerations might be more completely confirmed or modified by further experimental work. But after another year's consideration and experiment, I do not feel called upon to modify in any essential degree the statements or conclusions of the first paper; but rather to emphasize more clearly some of them which do not seem to have been clearly understood (perhaps, because they were too vaguely or imperfectly stated) by my critics.

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[1] AP. *J.* January 1895, 1, 52.

The logic and soundness of the assumption of constant resolution (or purity, which is directly proportional and at the limit equal to resolving power), rather than constant dispersion as a basis of comparison seems to have been generally admitted. The first point which is called in question is as to the relative advantages of large and small instruments of the same revolving power. Upon this point I think I was in some respects misunderstood by Professor Keeler. My contention was not that the small instrument was *universally superior* to the larger one, but that for *general* spectroscopic work it was equal to it in optical performance and superior to it in being lighter, more easily handled, and last but not least, cheaper, for very few astrophysicists can afford an instrument of 2 or even 1½-inch aperture.[1] The cost of construction diminishes very rapidly as the size of the instrument diminishes, for the cost of the Grubb[2] twelve-prism or the Young[3] ten-prism spectroscope of ⅜-inch aperture as listed by Grubb in his latest catalogue is only $250 for the former and $350 for the latter instrument, about one-tenth the cost of either the Lick or the Allegheny spectroscope. These instruments, however, are less complete in their arrangement than those designed by Professor Keeler, and are not provided with grating mountings, so that this great difference in cost is not entirely due to the difference

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[1] The Lick spectroscope and the Allegheny spectroscope are each of about 1⅜ inch aperture and each cost between $3000 and $4000.

[2] *M. N.* 31, 36. Schellen's *Spectralanalyse*, Vol. I.

[3] *Nat.* 3, 110.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

: will denote by L, is found by multiplying D by f', or,

$$L = Df' = \frac{r}{a} f'.$$

But for similar instruments $\frac{f'}{a}$ = const. and therefore for $=$ const., L is also constant or *the linear dispersion is the same* r *all sizes of instrument.*

The brightness of the spectrum is likewise the same for all pertures, and hence the time of exposure for a given photo- raphic plate will be the same.

The range of spectrum in a given angular width of field uld decrease as the aperture decreases, and hence if we were ited to a certain angular width, less of the spectrum could be tographed at once. But from a geometrical point of view re is no reason why we should be so limited, since photo- phic objectives can be used which give a field of sufficient ular aperture to embrace the *whole* length of the visible and a-violet spectrum under any condition of dispersion that ld practically arise.[1] The more important reasons why a e range of spectrum cannot be satisfactorily photographed single plate are, (1) the great difference in sensitiveness of plate for different wave-lengths and, (2) the great change of s (when lenses are used) a change which can only roughly compensated for by inclining the plate to the axis of the rving telescope. But I agree with Professor Keeler in con- ring that the larger instrument is on the whole more satisfac- for some particular purposes, of which this is one. These s were pointed out in a second paper[2] which dealt especially the design of some large instruments and which had been ten before Professor Keeler's article appeared. As I stated hat paper there is at least one case in which a large aperture is absolutely essential, *i. e.*, the case in which a very high resolving power (100,000 or more units) is necessary.

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[1] With three prisms of white flint the angular dispersion from A (index 1.55) to H x 1.6) is about 14°, and about twice this or 28° to the extreme ultra-violet. Con- ably less than half of this, however, could be photographed on the same plate for ical reasons.

[2] *Ap. J.* 1, 232, March 1895. See particularly p. 233. Also *Ap. J.* 2, 264.

Even granting that a grating of 40,000 lines per inch is practicable, this would require an aperture of 2½ inches to obtain the required resolving power in the first order. Professor Rowland has ruled satisfactory gratings as fine as 43,000 lines per inch,[1] but as a result of his long experience at Johns Hopkins he now recommends the use of gratings of from 10,000 to 15,000 lines per inch. With these gratings of course still larger apertures are necessary, unless spectra of higher orders than the first are used. So far in the comparison of grating spectroscopes of different apertures we have supposed that the same order of spectrum is used in different instruments, and if the brightness of the different spectra followed any uniform law, this would evidently be the true basis of comparison. But the fact that gratings may be obtained (though only by trial unfortunately) which have almost any desired anomaly, *i. e.*, are bright in almost any spectrum, gives the coarse-ruled grating a great advantage over the finer ruled gratings as respects its resolving power for a certain aperture.

Indeed, if we assume that the grating is placed in some particular position with respect to the axis of the spectroscope, *i. e.*, if the angles of incidence and diffraction are made constant, it is easy to show that the resolving power of the grating for light of any particular wave-length is *independent of the grating space* and depends only on the actual linear aperture of the grating.

For we have,—(using same notation as in previous article)

$$mn\lambda = a''(\sin\theta + \sin i)$$

and if θ, i, and λ are constant we have

$$mn = r = a''\ \text{const.}\dots.$$

which shows, as stated, that the resolving power of the grating depends only on the linear aperture. It would not matter whether the grating were ruled with 10 or 1000 lines to the mm., unfortunately is applicable only to the more intense of the bri lines of the spectrum and cannot be used for the examinatior absorption lines.

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[1] "Preliminary notice of results accomplished in the manufacture and theory of gratings for optical purposes." *Phil. Mag.* 13, 469.

The recent discoveries of Messrs. Jewell, Humphreys : Mohler, whose papers were published in the last number of JOURNAL makes the individual examination and measurem of the lines of celestial spectra a problem of the grea interest and importance, and one which demands more pov ful instruments than any that have yet been construct It is to be hoped that the difficulties which have heretof prevented the successful production of gratings larger t 6-inch aperture may soon be overcome, and that in the r future gratings of 10-inch, 12-inch, or even 15-inch and 18-i aperture may be constructed to go with the great refrac and reflectors now in use. Since gratings of 4-inch apert have been successfully used with telescopes of only 12-i aperture, it would seem that for the Lick and Yerkes telesco we ought not to be satisfied with less than a 12-inch or 15-i grating.

The last point of disagreement between Professor Kee and myself is in regard to the general design of the compou spectroscope. It seems to me that in every respect the reflec must be considered superior to the refractor for the purpose celestial, especially stellar, spectroscopy. The absence of ch matic aberration is not by any means the only or the chief adv tage; the freedom from absorption is perhaps quite as or even m important, particularly when work in the ultra-violet or infra- is in question; while the large field obtainable in spectrum w (all parts of the field being in focus at once); the coincidence the visual and the photographic foci; the much greater apert possible, combined with very short focal lengths and great co pactness; and finally the far less cost of the reflector as co pared with the refractor; these are all advantages of almost eq importance. The great disadvantage of the reflector, its se tiveness to flexure and consequent poor definition, is here of co paratively little importance, for it acts merely as a conden concentrating the light of the star on the slit. Moreover, there is but little doubt but what the definition of very large reflectors can be very considerably improved over what has generally been obtained in the past, by proper proportioning of parts and proper mountings.

This is a question which will soon be discussed by Professor Hale in another paper and will not therefore be taken up here. As already stated, the question of good definition is not so important in the case of the compound spectroscope as the question of size. Hence it may be quite possible to use for this purpose mirrors of cast iron or cast steel instead of glass, the surface of the cast metal being first worked to the proper curvature, and then covered with a thick coat of nickel electrolytically deposited to receive the final working and polishing.

The principal objection which Professor Keeler urged against the use of reflectors, particularly short focus reflectors, was that they necessarily implied the use of mirrors instead of lenses in the spectroscope train, a substitution which Professor Keeler considers "highly objectionable, as according to all experience a mirror cannot be depended upon when stability is required." My reasons for a contrary view, based upon both my own experience and that of others, are given at some length in the same article to which reference has already been made.[1] The importance of this question, however, will certainly justify my referring to this matter again and adducing some further arguments and recent experiments in support of my position.

In the first place attention may be called (1) to the fact that many modern meridian instruments (in which the greatest stability and permanence of adjustment are required) are of the broken-tube form, a reflecting prism or mirror being inserted between the objective and eyepiece; (2) that the plane and concave gratings which are now universally used in the most accurate measurements of wave-length are both essentially reflecting instruments; (3) and most striking of all that the various forms of refractometer and interferometer, with which such marvelously accurate measurements of various physical quantities have been made by Professors Michelson, Morley and others, are combinations of from three to seventeen reflecting surfaces, from some of which the ray is reflected twice, and any displacement of which during the course of the observations would introduce errors whose magnitude in comparison with the quantity measured would be enormously greater than any corresponding error due to the displacement of a mirror in an ordinary spectroscope train. Thus, for example, in the instrument used by Michelson and Morley in their experiments on the relative motion of the Earth and the luminiferous ether,[1] there were seventeen reflecting surfaces, from fifteen of which the light is reflected twice. The accuracy of measurement attained in this case corresponded to a change of position of one of the interference fringes by about $\frac{1}{100}$ of its own width, or a change in distance of about $0^{mm}.000003$. Since the aperture of the mirrors was about 50^{mm}, this change would correspond to an angular movement of any one of the seventeen mirrors (supposing the mirror to turn about one edge and the displacement of the fringe to be measured at the center of the field) of less than $\frac{1}{80}''$. Of course the displacements of the different mirrors might have happened to be compensatory, but the arrangement was such that they were just as likely to be all in the same direction, and in the latter case no one of them could have been displaced by as much as $0''.002$, a quantity far beyond the range of the most powerful astronomical telescope. It must be remembered also that in the case of these observations the whole optical system was in continuous rotation and that the distance between the successive mirrors was nearly two meters. The total time of observation extended over an hour or more, but the interval between two successive observations, during which accidental displacements might occur, was less than one-half a minute, so that these measurements, although showing conclusively the stability of the combination for short intervals, does not demonstrate it for long ones. But in some experiments which I have made with the recent forms of the instrument known as the wave comparer and the astronomical interferometer (the first of which has four, the latter six reflectors), these instruments have been left (exposed in the laboratory, which in one case was just above the instrument shop containing the engine, dynamo and a number of machine tools in constant operation) for from twenty-four to forty-eight hours without having changed in adjustment by an amount greater than at most 5′ of arc during the whole interval.[1] This shows, I think, conclusively that when mirrors are properly mounted and protected from such temperature changes as would seriously affect refracting instruments also, they may be depended upon to remain in practically perfect adjustment during the most prolonged exposures. For this reason I have thought it unnecessary in any of the instruments which I have recently described to make use of the double reflection prisms or mirror combinations shown in Fig. 6, in which the displacement of the prism is without effect on the angle of deviation of the doubly reflected ray.

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[1] See particularly pp. 242–3, *Ap. J.* March 1895.

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[1] *Am. Jour. Sci.* 34, 333.

If very great temperature changes or very serious vibrations were to be feared it might be advisable to make use of one of these forms, or of any other in which two successive reflecting surfaces are rigidly connected together.

I feel confident that the advantages of reflectors over refractors in spectroscopic work are so many and so great, and their disadvantages so few and so easily overcome by proper methods, that they will be used in the future far more than they have been in the past.

Most Advantageous Linear Dispersion for a given Aperture.—There is a point which has not yet been considered of special interest in the design of astronomical spectroscopes, particularly if they are to be used as spectrographs. This is as to the best linear dispersion to be given to any particular instrument. The angular dispersion for a given aperture and a given resolving power is a constant which is the same for both the prismatic and the diffraction spectroscope, and which is, in the one case, perfectly independent of the number or the refracting angle of the prisms, and in the other, perfectly independent of the fineness of the ruling or the order of the spectrum. As already shown, however, there is a definite relation between these last two sets of quantities, and *the aperture remaining constant*, a given dispersion (or given resolution, since the two quantities are, under the condition of constant aperture, exactly proportional), may be obtained in two ways: in the case of the prisms by use of a small number of prisms of large refracting angle, or by a large number of smaller refracting angles; in the case of the grating by the exactly analogous methods of employing a low order of a grating of a large number of lines per inch, or a high order of a grating of a smaller number of lines per inch. The relative advantages of these two methods in the case of prisms have been discussed in a preceding paper,[1] where it was shown that on the ground of compactness, simplicity and lightness it was preferable to use prisms of much larger refracting angle than at present employed—in some cases as high as 80°—the increased loss of light being very small, and in some cases even less than with the larger number of more acute angled prisms. The corresponding case for the grating is considered in an earlier part of this same paper (see pp. 180, 181).

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[1] The fringes disappear completely when the mirrors alter their adjustment as much as 1′ in the case of the first instrument and as much as 10′ in the case of the second.

The linear dispersion of the instrument, however, is variable with the length of the observing telescope, and the question is, how long is it desirable to make this; in other words, what should be the value of the ratio $\frac{a'}{f'}$. In observations with any optical instrument there are three properties with which we are concerned, viz., resolution, definition and accuracy. With regard to the first two there are two cases which must be considered: (1) that of visual observations, in which these properties are dependent upon physiological conditions; (2) that of mechanical registration by photography, bolometry, etc. In the first case, if the objective of the instrument were perfect, the performance would be independent of the ratio of focal length to aperture. Practically, however, the effect of aberration, which increases as the fourth power of the semi-angular aperture,[1] prevents the use of angular apertures greater than $\frac{1}{14}$ to $\frac{1}{19}$ in the case of single lenses of glass of from 25^{cm} to 1^{m} focal length, or greater than $\frac{1}{14}$ to $\frac{1}{10}$ for spherical mirrors of the same focal length. In compound lenses or parabolic mirrors this ratio may be increased, but not much beyond $\frac{1}{8}$ to $\frac{1}{7}$ in the case of lenses, or $\frac{1}{6}$ to $\frac{1}{4}$ in the case of mirrors. The longer focal lengths are also somewhat preferable, because they allow a given degree of magnification to be obtained with a lower power of eyepiece. For purely visual observations (not measurement) there is, however, no need of making the focal length more than ten times the aperture. In photographic or bolometric work the case is different, because of the finite size of the silver grains in one instance and of the bolometer strip in the other. It has been shown by Rayleigh[2] that two lines are just "resolvable" visually when the angular distance between them is such that the central maximum in the diffraction image of one coincides in position with the first minimum of the other. In this case the diffraction pattern due to the two lines (supposed to be of equal intensity) is that shown in Fig. 7. The intensity at the points *a* and *b*, the positions of the geometrical images, is about 1.23 times the intensity at *c*, the point midway between them. In order that these two lines may be distinguished in the photograph it is evident that the differences in density in the photographic image must be nearly as great as differences in intensity in the original diffraction pattern.[3] Hence the points *a*, *c*, *b*, Fig. 7, must fall on *separate* silver grains in the photographic film, and these silver grains must be sufficiently far apart to avoid the effects of photographic irradiation. A direct examination under a high power microscope of some solar negatives made on Seed 26 plates showed that in dense parts of the negative the reduced silver grains were practically in contact and on portions of average density the grains acted upon were separated by about their own diameter. Hence to eliminate the effect of irradiation in the one case and to obtain a normal action in the other, the grains a' b' c' should be separated by about their own diameter, *i. e.*, the distance from the center of a' to the center of b' should be equal to about four diameters of a' or b'. This enables us at once to determine the linear dispersion necessary to obtain the required resolution on a photographic plate. If we call e the mean diameter of the silver grains we must have

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[1] "A New Multiple Transmission Prism of Great Resolving Power." *Ap. J.* 2, 264, November 1895, see particularly pp. 271,272.

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[1] "Investigations in Optics," Lord Rayleigh, *Phil. Mag.* **8**, 411, November 1879. See also "Wave Motion," *Enc. Brit.*, 34, 431.

[2] "Investigations in Optics," *Phil. Mag.* **8**, 261, October 1879. See also "Wave Theory," *Enc. Brit.*

[3] Not quite as great, because if the negative is examined by transmitted light the diffraction in the observing microscope or eyepiece will cause the darker central strips to appear narrower and sharper than they would otherwise, just as in the use of a trans-

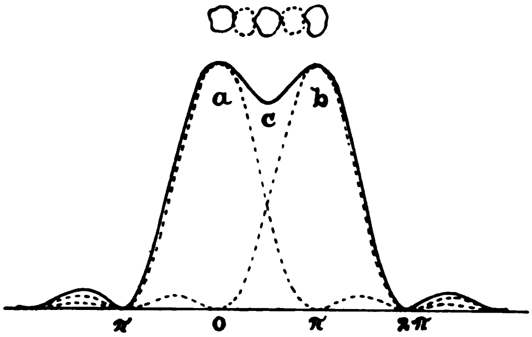

Fig 7

$$ab = 4e.$$

But, from the wave theory,

$$ab = \frac{m\lambda}{a'} f',$$

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parent galvanometer scale (black lines on a bright ground) lines may be separated whose angular distance apart is less than the resolving power of the galvanometer mirror. This same effect has also been observed and explained by Boys. "On the Newtonian Constant of Gravitation," C. V. Boys, *Phil. Trans.* 1895, A., 186, 1 (see p. 31).

where *m* is a const., which is equal to unity for a rectangular aperture of width a', and equal to about $\frac{5}{4}$ for a circular aperture of the same width,

$$\therefore \ \frac{a'}{f'} \equiv 0.3\frac{\lambda}{e}.$$

If we take as the mean diameter of the silver grains $0.^{\text{in}}0002$[1] the ratio $\frac{a'}{f'}$ becomes 0.03, or the focal length of the observing telescope ought to be about 35 times the aperture in order to obtain details as fine as can be recognized by the eye directly. There is, on the other hand, no great gain in photographic definition by increasing the focal length much beyond this point, certainly not in making it several hundred times the aperture as has been frequently proposed.

In the case of the bolometer the question is rendered more complicated by the fact that the resolving or discriminating power of the bolometer depends not only on the relative but also on the absolute differences in the spectrum. The consideration of this question in detail will soon be taken up. It is however evident that in general the distance between the geometrical images, *a, b,* must be at least equal to the width of the bolometer strip in order that the bolometer may recognize them as separate lines. Hence if we call the linear width of the bolometer δ, we have

$$\frac{a'}{f'} = 1.22\frac{\lambda}{\delta}.$$

Hence for a bolometer $0^{\text{mm}}.1$ wide, used in the region of wave-length $\lambda = 10{,}000$, the ratio of a' to f' should be about $\frac{1}{80}$.

For the purpose of accuracy it is also desirable to increase the focal length in order to magnify the width of the diffraction fringes with respect to the micrometer cross-wires. As is well known, the accuracy with which a cross-wire may be set on a fine line depends directly on the width of the central bright fringe of the image with respect to the cross-wire itself. The accuracy increases, other things being equal, until the width of the fringe is from 75 to 100 times the width of the cross-wire, after which it begins to fall off.[1] In an ordinary telescope it is not possible to magnify to this degree because of the decrease in the brightness of the image, but it is always advantageous to carry the magnification as far as possible, increasing the brightness when it can be done by placing a cylindrical lens in the eyepiece to contract the width of the spectrum as far as possible. To secure a fair degree of accuracy in setting, the central fringe should be at least ten times as broad as the cross-wire, and since the finest cross-wires have a diameter of at least $0^{mm}.003$ and the width of the central fringe for a circular aperture is

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[1] *Publications of the Lick Observatory*, 3.

$$w = 2.44 \frac{\lambda}{a'} f',$$

we have for the angular aperture under these conditions:

$$\frac{a'}{f'} = \frac{2.44\lambda}{.03} \equiv \frac{1}{25}.$$

Whence we conclude that both for purposes of photographic definition and accuracy of direct micrometric measurement, the focal length of the observing telescope should be at least thirty to forty times its aperture, or from two to three times its usual length. If the source is too faint to permit of so great a magnification, then the resolving power of the spectroscope should be decreased until the use of this ratio becomes possible.

This gives us a criterion for determining the maximum resolving power which can be used with advantage for a source of given brightness.

The necessity for this large ratio betweeen focal length and aperture is another strong argument for keeping the latter as small as possible. It will be noted also that it is of no advantage either for the purpose of photographic resolution or accuracy of measurement to simply increase the distance between the lines without increasing their breadth, and that therefore the use of a reversion prism or reversion objective is of little practical value in absolute spectrometric work, although ofttimes convenient in determining relative positions of different lines in the same spectrum.

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[1] "Measurement by Light Waves." A. A. Michelson, *Amer. Jour. Sci.* **39**, 115.

Various Forms of Prisms.—In all of the preceding discussions I have considered only simple prisms. None of the generality is lost, however, by such a discussion, because any compound prism (used in the position of minimum deviation), is simply equivalent to a train of simple prisms of some particular refracting angle, which in general will be more efficient in light transmitting power and in optical definition than the single compound prism. Indeed about the only advantage of the latter is in the reduction of the number of independent pieces in the spectroscope train, a reduction which is hardly worth the price paid. The half-prism is also far inferior to the train of simple prisms because of the greatly increased thickness of glass traversed for a given resolving power, and although half-prisms usually give very bright spectra, very elementary considerations will show that this is secured only at a great sacrifice of purity and resolving power. The superiority of trains of simple prisms was pointed out long ago by Lord Rayleigh,[1] but his excellent discussion of this and other points seems to have received less attention than it deserves at the hands of spectroscopists. His series of papers in the *Phil. Mag.* (1879–80) and his articles on Optics and the Wave Theory in the last edition of the *Enc. Brit.* which have been so frequently referred to, must form for many years to come the basis of all theoretical discussions of the design not only of spectroscopes but of optical apparatus in general.

RYERSON PHYSICAL LABORATORY,
UNIVERSITY OF CHICAGO,
January 1896.

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[1] "Investigations in Optics," Sec. 8. The Design of Spectroscopes, *Phil. Mag.* 9, 49, January 1880.

ON TWO SOLAR PROTUBERANCES, OBSERVED JULY 15 AND SEPT. 30, 1895.

By J. FÉNYI.

THE first of these phenomena was remarkable on account of the enormous velocity in the line of sight, reaching 858^{km} per second, which was observed at that time; the second on account of the vast height to which the protuberance rose, through the great velocity of its ascent. A height of 11′ 28″ was attained, with a mean velocity of 448^{km} per second.

On the fifteenth of July, at 7^h 10^m A.M., Greenwich Mean Time,[1] a very delicately formed prominence of 60″ height stood in position angle 272° 34′—261° 38′, corresponding to a heliographic latitude of —1° 14′ to —12° 10′ on the western limb of the Sun. It was precisely on the place where a considerable group of Sun-spots was passing out of sight (Plate XVI, Fig. 1). Along the entire base was visible the line λ6677, which is characteristic of regions of eruption. The most active region was at 266°, where, at 7^h 24^m, the *Hα* line (or, according to the older notation, the C line) appeared greatly widened, indicating a motion of 138^{km}; at the same place a small protuberance could be seen, even in the line λ6677. At 7^h 44^m, a very large motion in the line of sight was betrayed, at a small distance above the chromosphere, which, by measurement with the filar micrometer, amounted to 324^{km} recession per second; at the same time two cone-shaped projections appeared on the red side of the *Hα* line, which could not be seen in λ6677. While the displacements above mentioned were being measured, the form of the protuberance changed with extraordinary rapidity; Fig. 2 was drawn at 7^h 40^m. Still more rapid, however, were the changes in the forms produced by displacement, which, when the affected

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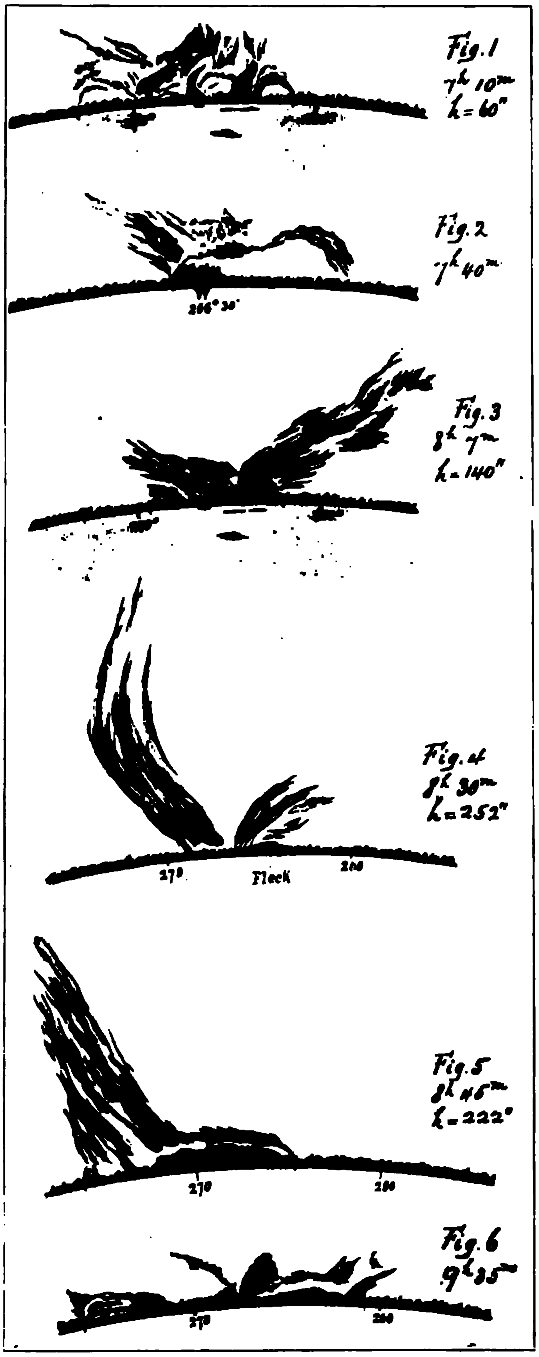
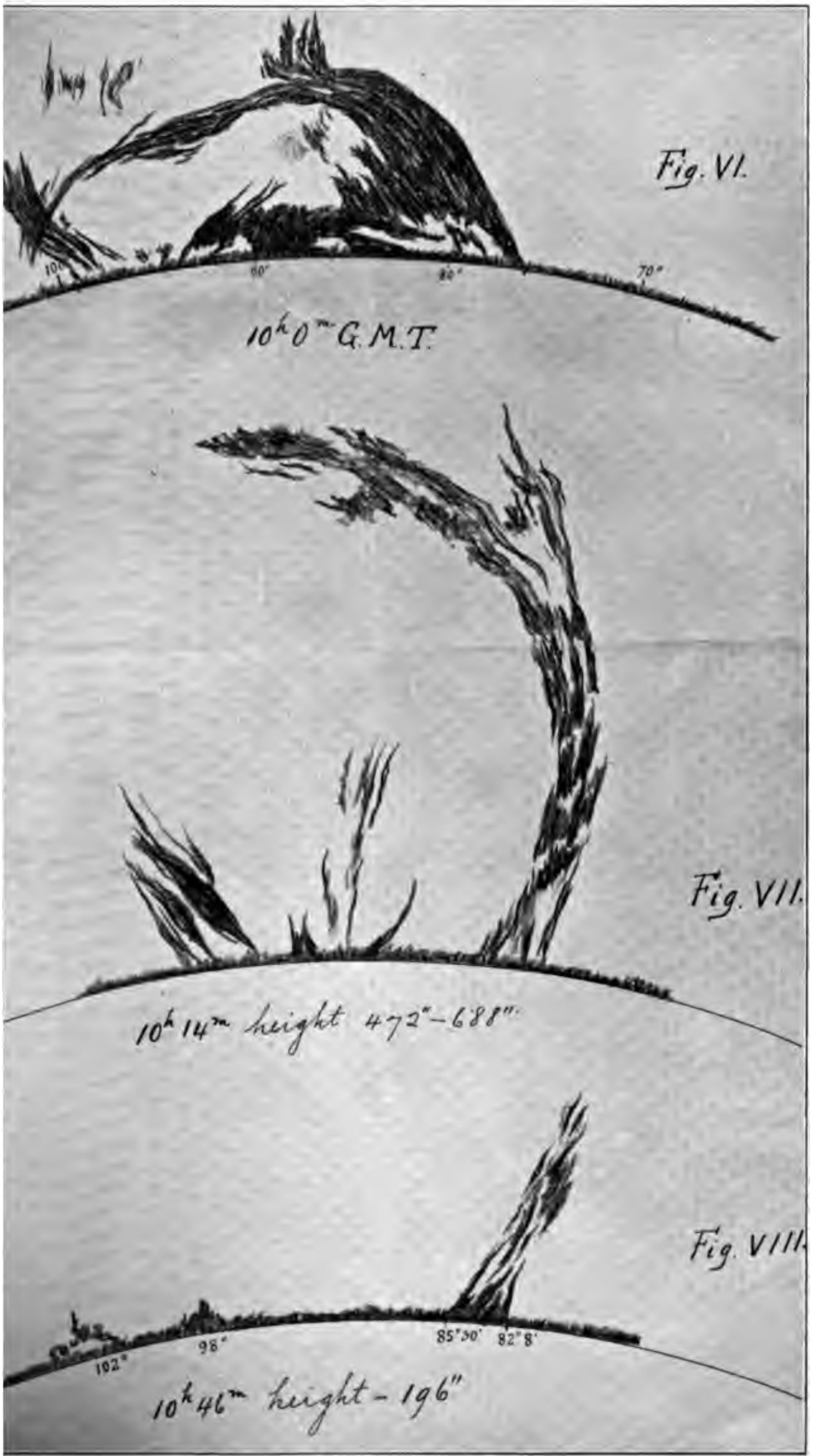
[1] Times are given in mean time of Greenwich, but according to the civil method of reckoning from midnight; the moment here referred to is therefore in astronomical reckoning July 14, 19^h 10^m G. M. T.

PLATE XVI.



ERUPTIVE PROMINENCE OBSERVED AT THE HAYNALD OBSERVATORY JULY 15, 1895.

PLATE XVII.



ERUPTIVE PROMINENCE OBSERVED AT THE HAYNALD OBSERVATORY SEPT. 30, 1895.

regions were caused to pass slowly over the the slit, appeared like tongues of flame flaring in the wind. Measurement of the displacements, to which my attention was now turned, gave the following velocities; they do not refer to precisely the same point, but are maximum values for this part of the protuberance.

A little before $7^h 50^m$, motion from us 483^{km}, toward us 303^{km} at the same place; at $7^h 50^m$, motion from us 526^{km}; the displaced light was entirely separated from *Hα*. At $7^h 55^m$, motion from us 771^{km}, and at the same time a motion toward us, two measures of which, uncorrected for slit-width, gave 512^{km}. The same displacement was visible in the line λ 6677. The greatest velocity was $858^{km}.8$ toward the Earth. The amount of the displacement at any moment was determined by measuring the distance from other spectral lines.

In the mean time the protuberance had assumed the form shown in Fig. 3. In the center of the eruption a protuberance $27''$ high could now be seen in λ 6677. The protuberance was sketched again; it had the form shown in Fig. 4, with a height of $252''$ at $8^h 30^m$. Three transits over the slit gave accordant values, from which it appears that the protuberance did not rise very rapidly, although it is also possible that dissolution at the summit kept equal pace with the ascent. The relative positions of the Sun-spots which are shown in the figure near the limb were observed directly in the spectroscope; the nearest spot was only $2''$ from the limb, exactly on the place 266° 30′ where the greatest eruptive activity had been displayed in the beginning. Fig. 5 was drawn at $8^h 48^m$; measurement of the height gave $222''$, with indications of ascent. This form remained nearly the same during the last quarter of an hour of observation.

I now proceeded with an examination of the rest of the limb, and on completing it, at $9^h 35^m$, found only a small protuberance on the first spot, with a height of perhaps $30''$. At $10^h 45^m$ the appearance was the same, and at $1^h 30^m$ P.M. the eruption had come to an end, after an existence of from $8^h 56^m$ to $9^h 35^m$.

The group of spots over which these phenomena we played had begun to develop rapidly a few days before.

The second protuberance, observed on September noticed at 10^h A.M. in the first stages of development. east limb of the Sun, in position angle 76° 26′ to 98° heliographic latitude + 17° 16′ to + 39° 42′, I found a inence of extraordinary brightness, the height of which then have been only about 60″. It is shown in Plate XVI VI, according to a very carefully executed drawing. The tion was remarkably good, but on account of the rapid cha the prominence, the drawing represents an average state observed form. Turning then to measurements of its he obtained 240″ at 10^h 11^m. The filar micrometer was use the height may be a little too great on account of the dis of the image; in order to see the whole prominence, the s to be opened to 2^{mm}.5, and the fact that this was possible t to the extraordinary brightness of the prominence. Af measurement was completed, its form had again com changed. Its more prominent features are represented VII, from a hasty sketch made at the telescope at 1 Seven successive transits across the slit were then observe ing which the ascent of the prominence was completed observed heights are given in the following table, with t responding times and computed velocities of ascent.

Measure	Greenwich Mean Time			Height	Velocity
	h	m	s	″	km
1	10	14	22.4	472	842
2		15	10.6	513	16
3		16	3.4	525	516
4		16	56.8	563	422
5		17	50.0	594	221
6		19	2.0	616	746
7		20	11.0	688.3	
8		20	59.6	493 (uncertain)	
9		29	20.0	525 "	
10		30	13.0	398 "	
11		46	39.	196	

While the protuberance was passing across the son narrowed slit, I noticed in many places considerable displacements, sometimes toward the red and sometimes toward the violet. The small clouds, which may be seen in the drawing floating above the principal mass, rose with especial rapidity, and indicated a large motion of recession,—according to one measurement 181^{km} per second. The fragments endowed with this extraordinary motion were found above the great arch shown in Fig. VII, in a position angle of approximately 95°; when the third transit was observed they had already faded greatly, so that some uncertainty attaches to the height obtained for them. At the eighth transit they could no longer be observed. The height obtained was only 493″; further transits gave 525″ at 29^{m} 20^{s}, and 398″ at 30^{m} 5^{s}, but these last values are quite uncertain, and are added merely to show that the highest parts of the protuberance were rapidly dissolving. At 10^{h} 47^{m} the height reached by the part inclined toward the equator (Fig. VIII) was 196″. The other parts had already vanished, as shown by the figure, and at great heights also nothing could be detected. At 3^{h} 45^{m} a new prominence, consisting of very bright flame-like filaments, had risen over position angle 93°–96° to a height of 60″, and at 83° there was visible only a small prominence about 20″ high. The entire colossal form therefore developed in an interval of twenty minutes, and had dissolved with still greater rapidity. The velocity of ascent seems to have altered incredibly in the short interval of 1^{m}–2^{m} between the observations, and it is probable that these changes are rather to be ascribed to inequalities in the rate of dissolution at the summit. The particularly striking change indicated by the second transit would be satisfactorily accounted for, if it were allowable to assume an error of one second in the noted time—an assumption, however, for which no justification can be discovered in the observations themselves. Instead of the velocities given in the table (842, 16, 516^{km}), we should then have 391, 355, 516^{km}.

Although the individual velocities may be subject to some uncertainty on account of the dissolution which accompanied the rise of the prominence, we have, in the mean value of the ascent during the eight minutes occupied by the seven transits, an average result from which trustworthy conclusions may be drawn. From an ascent of 216″.3 in $349^{s}.6$ we obtain a velocity of 448^{km} per second, which is a minimum value, depressed by the effect of dissolution. A correction of 4″–5″ should really be added to the height 688″.3, increasing the value of the latter, since the highest fragments of the prominence did not pass exactly over the part of the slit which was tangent to the Sun's limb, but the correction is in this case of no importance. If we use the earlier observations, for which the times are less accurate, to determine the velocity, the values obtained are very materially greater.

The Sun-spot connected with this latter eruption betrayed a considerable motion in longitude, and I therefore caused my assistant, Herr P. J. Schreiber, to whom the observations of Sun-spots are entrusted, and who made the accompanying drawings of spots, to determine its exact position at different times. On September 30 the longitude was 303°.5 and the latitude + 21°.3. The following table gives the difference between the observations and Spörer's rotation formula:

Sept. 30 to Oct. 1	— 1°.25
Oct. 1 to Oct. 2	— 1 .35
Oct. 2 to Oct. 3	— 0 .59
Oct. 3 to Oct. 4	— 0 .43
Oct. 4 to Oct. 5	+ 0 .36
Oct. 5 to Oct. 6	— 0 .59
Oct. 6 to Oct. 7	+ 0 .17

It appears, therefore, that in the earlier days there was in fact a considerable proper motion of the spot, amounting to about 600^{km} per hour.

In both of the cases, which have been described above, we find eruptions standing in close relationship to a group of Sun-spots very nearly on the limb of the Sun. Eruptions on a great scale occur only in the Sun-spot zones, usually, but not always, over a disturbed region of spots. Especially deserving of attention is the grouping of the component strips of the prominence in forms so exactly inclined to the Sun-spot group, and the coresponding disposition of the phenomenon during its entire ourse. There is nothing new in the convergence of the strips oward the Sun-spot; an appearance of this kind, more or less marked, is always observed over a spot in the course of development on the Sun's limb, so that from this characteristic structure of a prominence the approach of a spot to the eastern limb of he Sun can be predicted. In the cases before us the phenomenon is especially striking, and leads to the supposition that processes of less intensity, but not essentially different nature, are going on above the spots which we daily observe on the face of the Sun.

In forming a judgment as to the nature of the phenomena we must account also for these appearances. The strips which are so characteristically inclined must have a radial arrangement with reference to the spots, in which the central strips are hidden or shortened by perspective, while those on the sides are strengthened by superposition. It cannot be denied that this arrangement points to the existence of currents in the solar atmosphere, directed either toward the interior of the spot or outward from it. n view of the appearances which accompany the ascent of erupive prominences, we must, if we wish to avoid the assumption of ppositely directed motions in close proximity, consider an outward current as the more probable. We need not therefore also ssume that monstrous protuberances, which in extreme cases may even attain a volume equal to the tenth part of the Sun's, ow out through the small center of the spot from the interior regions, although the enormous extent does not offer any absoute difficulty. Direct observation simply does not support such n assumption. Although we almost always see protuberances ising from a broad base as a uniform mass, this fact can also be explained by supposing that the foot of the protuberance is not on the solar limb; but those regions which by the intensity of their phenomena make themselves known as centers of eruption, and which by their inconsiderable height are visible only when they are exactly on the limb, are almost never observed over a spot, but usually close beside it.

The appearance of all the numerous great eruptions which I have observed has been such as would be produced by a kind of explosion over a region of spots, which, seizing upon a prominence already developed, hurls it upward from the surface, tears it to pieces, and brings it to a speedy end. This conception also accords well with the appearances which we are now considering; it is by no means asserted, however, that an explosion actually occurred.

A remarkable example apropos to this subject is afforded by the eruption of September 5, 1888. I had observed the eruptive region over half an hour, on account of the metallic lines which appeared in it, without noticing any change; suddenly, in about one minute, the prominence, which was only about 20″ high, began to rise, and in an interval of nineteen minutes it reached a height of 111,000^{km}. Often great prominences, which had remained almost unchanged for days, could not be found a few hours later; only the clear edge of the Sun was in their place — not a fragment of them remained.

These phenomena are interpreted in very different ways. I have little fear of being mistaken when I say that there is not a single observer of prominences who regards any one of the later theories as tenable.

That enormous translatory velocities of 200 and more kilometers per second occur in the matter on the Sun, I regard as definitely proved by the observed displacements of spectral lines, and if these great horizontal velocities are admitted, vertical motions of the same order are not to be set aside as incredible. A very weighty objection to the occurrence of vertical changes of level has recently been brought forward and numerically treated by Herr Egon v. Oppolzer. He shows that even moderate changes of level of only 1″ are sufficient to cause a difference of temperature of 13,000°, in consequence of the adiabatic changes of pressure. According to this computation, the protuberance of September 30 must have cooled some 9,000,000° in rising to a height of 688″. Herr v. Oppolzer's argument is directed against the possibility of a gaseous mass *sinking* toward the Sun; a sinking motion must, if rapidly begun, be resisted by the elevation of temperature. On the ground of observation I can only confirm this result of computation in the most emphatic manner; downward motions are in fact, very seldom observed in prominences, and may then arise from quite peculiar conditions. In general, the falling back of masses which have been thrown upward, an occurrence so familiar in our daily experience, is never observed on the Sun. Although observers occasionally speak of forms resembling a fountain, no more significance should be ascribed to such a comparison than to the tree-like forms which are more frequently mentioned. The difficulties which the researches of Herr v. Oppolzer have opposed to ascending as well as descending motions will constitute one of the objects of my investigations, of which I shall hope to say more in the near future.

KALOCSA, HUNGARY,
December 4, 1895.

THE ALGOL VARIABLE *B. D.* + 17° 4367.

By EDWARD C. PICKERING.

BELOW are given the heliocentric times of minima of the Algol star *B. D.* + 17° 4367 expressed in Greenwich Mean Time during the year 1896. They are computed by means of the formula, *J. D.* 2412002.500 + 4.8064 *E*. It is not probable that the period will be changed materially by later observations, but the times of minima may be altered by a constant amount of several minutes if the rates of increase and decrease are different. For nearly two hours before and after the computed minima the star may be expected to be fainter than the twelfth magnitude, two magnitudes and a half fainter than its normal brightness, and varying very rapidly. The value of *E* for the first date is 325 and for the last 400.

Jan.	5	13^h	55^m	April	5	21^h	38^m	July	6	5^h	21^m	Oct.	5	13^h	05^m
"	10	9	16	"	10	16	59	"	11	0	43	"	10	8	26
"	15	4	37	"	15	12	20	"	15	20	04	"	15	3	47
"	19	23	58	"	20	7	42	"	20	15	25	"	19	23	08
"	24	19	20	"	25	3	03	"	25	10	46	"	24	18	29
"	29	14	41	"	29	22	24	"	30	6	07	"	29	13	51
Feb.	3	10	02	May	4	17	45	Aug.	4	1	29	Nov.	3	9	12
"	8	5	23	"	9	13	06	"	8	20	50	"	8	4	33
"	13	0	44	"	14	8	28	"	13	16	11	"	12	23	54
"	17	20	06	"	19	3	49	"	18	11	32	"	17	19	15
"	22	15	27	"	23	23	10	"	23	6	53	"	22	14	37
"	27	10	48	"	28	18	31	"	28	2	15	"	27	9	58
Mar.	3	6	10	June	2	13	52	Sept.	1	21	36	Dec.	2	5	19
"	8	1	31	"	7	9	14	"	6	16	57	"	7	0	40
"	12	20	52	"	12	4	35	"	11	12	19	"	11	20	01
"	17	16	13	"	16	23	57	"	16	7	40	"	16	15	23
"	22	11	34	"	21	19	18	"	21	3	01	"	21	10	44
"	27	6	56	"	26	14	39	"	25	22	22	"	26	6	06
April	1	2	17	July	1	10	00	"	30	17	43	"	31	1	27

HARVARD COLLEGE OBSERVATORY,
Cambridge, Mass., February 3, 1896.

PRELIMINARY TABLE OF SOLAR SPECTRUM WAVE-LENGTHS. XII.

By HENRY A. ROWLAND.

e-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
.010		0000	6105.995		000
.186		0000	6106.651		0000
.287		0000	6106.840		00
.429	Fe	2	6107.070		0000
.722		0000 N	6107.309		0000
.395		0	6107.560		0000
.580		0000	6108.108		0000
.714		0000	6108.334 s	Ni	6
.945		000	6108.503		0000
.133		1	6108.675		0000 d?
.737		0000	6109.105		0000
.030		000	6109.545		0000
.366		00 N	6110.042		0000
.580	A?	0000	6110.555		0000 d?
.864	Fe	2	6111.005		0000
.075		0000	6111.290 s	Ni	2
.590	Fe	1	6111.545		0000 N
.118		0000	6111.872	V	0 d?
.575		0000	6112.235		0000
.360		0000 N	6112.500		0000 N
.880	Fe	3	6112.621		0000
.095		0000	6113.142		0
.312		0000	6113.340		0000
.505		000	6113.538		0
.000		0000	6114.075		0000
.465		0	6114.600		0000 N
.870		00	6115.010		0000
.888		0000 N	6115.960		000 N
.490		00	6116.268		0000
.392 s	Fe	6	6116.397 } s	Ni	4
.635		0000 N d?	6116.455 }	Fe	1
.937 s	Ca	9	6116.665		0000
.289		0000	6116.900		0000Nd?
.400 } s	Fe	4	6117.210		00
.514 }		1	6117.415		000
.690		000	6117.623		0000
.796		0000	6117.846		0000
.830		0000	6118.028		0000
.349		0	6118.139		0000
.730		0000	6118.320		000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
6119.385		0000	6136.829 s	Fe	8
6119.527		0000	6137.210	Fe	3
6119.740	V	1	6137.428		0000
6119.970	Ni	0	6137.505		000
6120.245		0000	6137.710		000
6120.460		00	6137.915	Fe	7
6120.751		0000	6138.266		0000 N
6121.010		0000	6138.725		00 N
6121.215		000	6139.864		000 N
6121.541		0000	6141.020		0000
6121.986		0000	6141.265		000
6122.434 s	Ca	10	6141.595		0000
6122.830		000	6141.938 s	Fe, Ba	7
6123.468		0000	6142.225		0000
6123.730		0000	6142.420		0000
6124.287		0000	6142.700		1
6124.703		0000	6143.044		0000 N
6125.236		1	6143.390		0000 N
6125.522		0000	6143.976		0000 N
6126.075		0000 N	6144.550		0000
6126.435	Ti	1	6144.988		0000
6126.665		0000	6145.228		2
6127.001		0000	6145.616		000 N
6127.684		0000 N	6146.445		000
6127.851		0000	6146.882		0000
6128.124	Fe	3	6147.380		0000 N
6128.320		0000	6147.702		0000
6129.190	Ni	1	6147.950		2
6129.430		000	6148.040	Fe	3
6129.740		000 N	6148.300		0000 N
6129.940		000	6148.480		0000
6130.145		0000	6148.870		000
6130.344	Ni	1	6149.209		0000
6130.560		0000	6149.458		2
6131.181		0000 N	6149.766		0000
6131.490		0000 N	6149.950		0000 N
6131.785		0	6150.360	V	0 N d?
6132.070		0	6150.840		0000
6132.490		0000 N	6151.052		0000
6132.704		0000	6151.550		0000
6133.020		0000 N	6151.834	Fe	4
6133.440		000 N	6152.054		0000
6133.785		0000 N	6152.226		0000
6134.175		00	6152.520		0000 N
6134.810		000 N d?	6152.854		0000
6135.280		0000 N	6153.055		0000
6135.580	V	00 N	6153.560		0000 N
6135.985	Cr	00 N	6154.129		0000 N
6136.280		0000	6154.438 s	Na	2
6136.500		0000	6154.650		0000

Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
	0000 N	6173.276		0000 N
	0000	6173.553 s	Fe	5
	7	6173.782		0000
	000	6174.065		0000
	0000	6174.948		0000 N
	000	6175.370		0000
	00	6175.584	Ni	3
	000 N	6175.807		0000 N
	000 N	6176.011		0000
	0000 N	6176.426		0000
	000	6176.669		0000
Fe	5	6176.815		0000
	0000	6177.027 s	Ni-	5
	000 N	6177.255		0000
	0000	6177.463		0
	0000	6177.747		0000
	0	6177.977		0000
	0000 N	6178.730		0000 N
	0000	6179.610		000
	0000	6180.279		0000
Na	3	6180.420 s	Fe	5
	0000	6180.587		0000
	0000	6182.849		0000
Ca	4	6183.334		0000
	0000 N	6183.779	-, A (wv)?	0 Nd?
Ca	15	6184.080		000
Ni	2	6185.918	Fe	1
Fe	1	6186.424	-, A (wv)?	00 N
Ca	3	6186.928	Ni	2
	0000 N	6187.618		00
	0000	6188.210	Fe	4
Fe	3	6188.679		0000 Nd?
	0000	6189.200	Co, A (wv)?	00 Nd?
	0000	6189.594		0000 N
	0000	6190.611		000
	0000	6190.873		0000
Ca	5	6191.048		0000
	0000 N	6191.393 s	Ni	6
	0000	6191.779 s	Fe	9
Ca	6	6194.440		0000
	0000	6194.633		0 N
Ca	7	6195.080		0000
	000 N	6195.663		0 N
V	0000 N	6196.373		0000
Fe-Ni	6	6198.107		0000
	0000	6198.864		0000
	0000	6199.398	V	0
	0000	6199.718		00
	0000	6199.985		0000
	0000 N	6200.160		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
6200.527 s	Fe	6	6230.551		0000
6200.690		0000	6230.943 s	V-Fe	8
6201.176		0000	6231.211		0000
6203.554		0000	6232.856	Fe	3
6204.698		0000	6233.082		0000
6204.825	Ni	1	6233.408		000
6205.360		0000 N	6233.720		0000Nd?
6207.460		000	6236.816		0000 N
6207.916		0000	6237.534 s		3
6208.425		000	6238.598		2
6208.783		00	6239.234		0000
6209.100		0000	6239.585		00
6209.962		0000 N	6239.980		0000
6210.895		00 N	6240.165		00
6212.275		00 N	6240.370		0000
6212.479		0000	6240.530		00
6213.644 s	Fe	6	6240.863	Fe	3
6213.840		0000	6241.065		0000
6214.080	V	000	6243.055	V	000
6214.885		000 N	6243.320		1
6215.231		0000	6243.540		0000 N
6215.360	Fe	5	6244.033		2
6215.630	Ti	000	6244.335		000 N
6215.931		0000	6244.686		2
6216.103		00 N	6245.137		0000 N
6216.567		1	6245.413		0000 N
6216.810		0000	6245.832		1
6217.900		000	6246.100		0000 N
6219.494 s	Fe	6	6246.535 s	Fe	8
6219.730		0000	6247.774		2
6220.150		0000	6249.122		000
6220.450		000	6249.409		0000
6220.700		000	6249.710		0000
6221.005	Fe	0	6249.860		000
6221.222		0000	6251.495		0000
6221.552	Fe,-	00 Nd?	6252.048	V	00
6221.850		0000	6252.278		0000
6223.652		0000 N	6252.410		0000 N
6224.198	Ni?	1	6252.773 s		7
6224.407		0000	6254.050		00
6224.715	V	000	6254.382 } s		1
6225.380		0000 N	6254.456 }	Fe	5
6225.700		0000	6255.000		0000 N
6226.527		0000 N	6255.805		0000 N
6226.951	Fe	1	6256.168	Fe	00
6227.770		00	6256.572 s	Ni-Fe	6
6229.437	Fe	1	6257.090		0000 N
6229.852		0000	6257.802		0000 N
6230.050		0000	6258.322	Ti	2
6230.312	Ni	0	6258.570	V	000 N

Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
	00	6278.012		000
Ti	3	6278.177	A(wv)	0000
	0000	6278.303[2]	A(O)	4 d
	0000	6278.579	A(wv)	00 N
	00	6278.760		0000
	0000	6278.907		0000
Ti	1	6279.084	A(O)	2
V	0000	6279.308	A(O)	3
	0000 N	6279.530	A(wv),-	00 Nd?
	0000	6279.754	A(wv)	0000
	0000 N	6279.946		0 d
	0000 N	6280.108	A(O)	2
	0000	6280.305		0000
Fe	5	6280.460		0000
	0000	6280.598	A(O)	2
	000	6280.833	Fe	3 d
	0000 N	6281.025		0000
	000	6281.228		0000
	0000	6281.387	A(O)	1
	0000 N	6281.575		0000
-, A (wv)	000	6281.835		000 N
	000	6282.004		0000
	0000	6282.164	A(O)	2
	0000	6282.350	A?	0000
V	000 N	6282.502		0000
	0000	6282.740	A(wv)	000
	000	6282.808		000
Fe	3	6282.933	Co- A (O)	2
	0000	6283.035		000
	0000 N	6284.002	A(O)	1
Fe	0	6284.210		0000
	0000	6284.748	A(O)	0
	000	6284.993		0000
A(wv)	0000	6285.384	V	00 N
A(wv)	000	6285.878		0000 N
	000	6286.031	A(wv)	00
	0000 N	6286.359		0
	000 N	6287.009		0000 N
	00	6287.494		000 N
A(wv)	000	6287.953[3]	A(O)	1
	0000 N	6288.154	A(wv)?	000 N
	0000	6288.530		000 Nd?
A(O)	2 d	6288.839		0000
A(O)	1	6288.955		0000
A?	00 N	6289.384	A(wv)?	000
A?	000	6289.606	A(O)	1
A(O)	2	6289.790		0000
A(O)	1	6290.106		0000 N
A(O)	1	6290.427	A(O)	2
A(O)	1	6290.750		000 N

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line in the head of the alpha group, due to atmospheric oxygen.

ipal line in the head of the alpha group.

line in the tail of the alpha group.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
6291.184	Fe	4	6308.090		000 N
6292.373	A (O)	2	6309.040		000 N
6292.572		0000	6310.101	A (O)	2
6292.825	A (wv)	0000 N	6310.487		00 Nd?
6293.030	V	000	6310.698		0000
6293.170	A (O)	3	6310.848	A (O)	1
6293.370		0000	6311.055		0000
6294.155		00 Nd?	6311.451		00 Nd
6294.875	A (wv)	0000 N	6311.722	Fe	1
6295.242		0000	6311.936		0000
6295.389	A (O)	3	6312.456		00 N
6295.590		0000	6312.980		000
6295.860	A (wv)	0000 N	6314.077		0000
6296.022		0000	6314.449	A (O)	0
6296.170	A (O)	3	6314.876	Ni	4
6296.360		0000	6315.189	A (O)	0
6296.582	V	0000	6315.517	Fe	2
6296.715		0000	6315.631		00
6297.471	A (wv)?	0000	6315.854		000
6297.517		0000	6316.028	Fe	1
6298.007	Fe	5	6316.245		000
6298.295		0000	6316.510	A (wv)	000
6298.513		0000	6316.816		000
6298.666	Co, A (O)	2	6317.440	A (wv)	0000
6298.854		0000	6317.670		0000
6299.436	Fe, A (O)	3	6318.239	Fe	6
6299.625	A (wv)	000	6318.524		0000
6299.805		0	6318.919		1
6300.535		000	6319.082	A (O)	0
6300.904		000	6319.274		0000
6301.718	Fe	7	6319.460		0
6302.056		0000	6319.690	-, (wv)?	000
6302.209	A (O)	2	6319.806	A (O)	0
6302.401		0000	6320.250	A (wv)	0000 N
6302.709	Fe	5	6320.660		000
6302.975	A (O)	2	6321.070		00
6303.159		0000	6321.505	A (wv)	0000
6303.700		000 N	6322.380	Ni	0
6303.985		000 N	6322.550		0000
6304.545		000 N	6322.907	Fe	4
6305.070		0000 N	6323.244		0000 N
6305.525		000 N	6323.688		0000 N
6305.878		0000	6323.957	A (O)	00
6306.024	A (O)	2	6324.096	A (wv)	0000
6306.201		0000	6324.709	A (O)	00
6306.430		0000	6324.894		0000
6306.619		0000	6325.382		0000
6306.780	A (O)	2	6325.748		0000 N
6306.950		0000	6327.038		0000
6307.763		0000 N	6327.485		0000

FLUORESCENCE OF SODIUM AND POTASSIUM VAPORS AND ITS SIGNIFICANCE IN ASTROPHYSICS.[1]

By EILH. WIEDEMANN and G. C. SCHMIDT.

IN the case of unmixed vapors fluorescence has been proved to exist for iodine by E. v. Lommel,[2] and we have shown[3] that it also exists for the vapors of numerous organic substances. In our recent experiments we have studied the behavior of metallic vapors with respect to the same property.

I. ARRANGEMENT OF APPARATUS.

The arrangement of the apparatus used in these experiments was as follows: Rays of sunlight fell upon a lens L of about 5^{cm}, focal length, by which they were converged to a focus σ inside a spherical bulb K filled with vapor. At one side of the bulb was placed a spectroscope fastened by its legs to a vertical board in such a position that the slit and refracting edge of the prism were horizontal. The conical bearing in its base allowed the spectroscope to be turned on its axis, so that the collimator

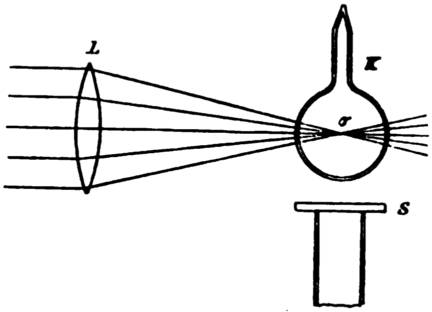

FIG. 1.

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[1] "Fluorescenz des Natrium-und Kaliumdampfes und Bedeutung dieser Thatsache für die Astrophysik."—*Sits. d. Phys. med. Soc. Erlangen*, November 12, 1895.

[2] *Wied. Ann.* **19**, 856, 1883.

[3] *Wied. Ann.* **56**, 18, 1895.

could be directed to the cone of fluorescent light in the interior of the bulb.

The introduction of sodium, potassium and other metals into the bulbs, which were usually made of hard glass, was effected in the following manner:

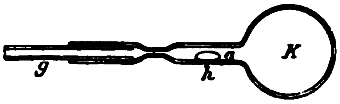

FIG. 2.

A small quantity of metal was first placed in the bulb; the neck was then drawn out, and a tube of soft glass cemented into its end, connecting it with a mercury air-pump. The metal was then brought into the position *a*, and gently heated during continuous pumping, in order to drive out all moisture and carbon dioxide, while in some cases the bulb was also cleansed by filling it several times with hydrogen. The heat was then increased, and after a suitable quantity of metal had distilled over into the bulb *K*, the neck was sealed off at its narrowest part by melting. In most of the experiments the diameter of the bulb was 5^{cm}, so that the whole bulb was easily enveloped in a flame. We have also used bulbs of soft glass, and bulbs of other dimensions than the above, but the optical phenomena were always the same. In the case of the alkali metals much trouble was caused by the changes which their vapor produced in the glass, even in short periods of time; the bulbs blackened and browned so that they frequently had to be replaced by new ones.

2. RESULTS.

The experiments showed that sodium and potassium vapors have a bright fluorescence,—the former green, the latter deep red. The fluorescence of these vapors can also be seen very beautifully when they are introduced into the arc of an electric lamp.

In the case of the less volatile metals we have so far been unable to demonstrate the existence of fluorescence with entire certainty, although cadmium vapor seems to show a green fluorescent color immediately over the surface of the boiling metal. The failure of these attempts is however to be attributed in part to the feeble intensity of winter sunlight, and we shall naturally repeat the experiments in the summer.

The spectrum of the fluorescent light of sodium vapor is constituted as follows:

——λ 496.	Above λ 496 almost nothing can he seen.
λ 496 —λ 540.	Green fluted band, made up of separate dark and bright lines.
λ 540 —λ 602.5.	Dark band.
λ 602.5 —λ 675.	Bright red band.
λ 675.	Limit of the red.

In addition the bright sodium line appeared at the less refrangible end of he dark band λ540—λ602.

The bright sodium line did not come from the flame used or heating the bulb, for it remained brightly visible when he flame was removed; nor did it arise from chemical processes going on in the bulb, for it disappeared instantly on cutting off he sunlight.

The spectrum of the fluorescent light of sodium vapor[1] is herefore made up of three parts: (1) The non-fluted band in he red, (2) the fluted band in the green, (3) the bright sodium ine in the yellow.

While solid and liquid fluorescent bodies have fluorescence spectra which consist of broad, diffuse, continuous bands, we here meet with fluted bands also, such as are shown by other gases under the influence of the electric discharge, and with single lines.

The fluorescence spectrum of potassium has a deep red band at λ615—λ695. Above this the background is dark, although there is a slight brightening in the green, due, perhaps, to the presence of some sodium vapor.

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[1] A comparison of these fluorescence spectra with the spectra which appear when sodium vapor is heated (Evershed, *Phil. Mag.* (5) **39**, 460, 1895), shows the existence of certain relations, and the same is the case, with both sodium and potassium, if the positions of the fluorescence spectra are compared with the absorption-band spectra measured by H. E. Roscoe and A. Schuster (*Proc. Roy. Soc.* **22**, 262, 1894); in both cases the emission spectrum seems to be displaced toward the red.

We were unable to prove that the bright potassium lines were present, but their absence may have been due to insufficient intensity of the incident light.

The spectrum of the fluorescent light of lithium could unfortunately not be observed, since lithium, when it is heated in glass vessels, attacks the glass, with production of light. On further heating the vapor given off by the residue shows merely the green fluorescence of sodium. Attempts to obtain an electro-luminescence from lithium, enclosed in vacuum tubes and subjected to electric discharges, were unsuccessful for the same reason.

3. VALIDITY OF STOKES' LAW FOR THE FLUORESCENT LIGHT OF METALLIC VAPORS.

We have also tried to ascertain whether Stokes' law holds good for metallic vapors, *i. e.*, whether the excited rays of light are less refrangible than the exciting rays. To this end a somewhat narrow strip in the spectrum formed by a prism was isolated by screening out the other rays, and its light was concentrated by a lens on the vapor which filled the bulb.

With sodium vapor the intense green fluorescent light was excited most powerfully by green-blue rays, and the red by yellow and red rays. With potassium vapor the deep red light was excited by red rays.

These experiments show that there were at least no very marked deviations from Stokes' law.

4. APPLICATIONS TO ASTROPHYSICS.

We desire to point out briefly the importance in astro physical problems of the observations which are described above and which show that metallic vapors are capable of exhibiting fluorescence. A more complete discussion must be reserved for another place.

We know that the Sun's atmosphere contains the vapors of different metals, which are illuminated by the Sun; they must therefore fluoresce, and that very brightly. We must not forget that the intensity of the exciting light in the vicinity of the Sun is very much greater than at the surface of the Earth, and hence, also, that of the fluorescent light which is excited. These radiations due to fluorescence do not obey Kirchhoff's law.

The emitted fluorescent light is made up of continuous and fluted bands and single lines. In the case of a mixture of many different metals the bands would blend together into a continuous spectrum; the delicate, and often scarcely perceptible flutings of different substances would be superposed and lost. The sharp lines, on the other hand, would remain separately visible. In this way we should have, for example, the simplest possible explanation of the spectrum of the corona, which consists of a continuous spectrum and individual bright lines. It would then be unnecessary to assume a continuous excitation of luminosity by electrical vibrations, which nevertheless in many cases certainly play an important part. Applications of these results to the theory of the chromosphere, certain forms of prominences, etc., readily suggest themselves.

But in all astrophysical and other phenomena relating to radiation an especial discussion will be necessary, not only with reference to what part of the radiation arises solely from an elevation of temperature, and what part from luminescence, but it will also be necessary to determine when we have to deal with a luminescence excited by light, *i. e.*, with fluorescence. Here the conditions are comparatively simple and more easily realized than in other cases within the reach of experiment.

5. GENERAL REMARKS.

The fluorescence that we have investigated, that of rarified potassium and sodium vapors, may be the simplest possible case of this phenomenon. In the first place the light-emitting molecules of the body under investigation, when it is in the gaseous state, are almost uninfluenced by the action of neighboring molecules,—if we except the short times when two or more molecules are mutually within the spheres of their respective attractions, in which instants their relations are those of molecules in solid and liquid bodies. Further, sodium and potassium vapors are monatomic, at least according to the determinations of vapor densities which have been made hitherto. The fact that these vapors can give banded as well as line spectra constitutes a new point of departure for theoretical investigations of fluorescence, especially when it is desired to take into account the intramolecular processes which are the cause of the phenomenon.

6. RESULTS.

The fluorescence of sodium and potassium vapors is bright; the former green, the latter red. The fluorescence spectrum of sodium vapor contains continuous and fluted bands, and also the yellow line of sodium.

Stokes' law is probably valid for the fluorescence of metallic vapors. The fluorescence of metallic vapors gives a means of explaining a series of astrophysical phenomena.

(Experiments with helium and argon are in progress.)

MINOR CONTRIBUTIONS AND NOTES.

HARVARD COLLEGE OBSERVATORY, CIRCULAR NO. 5.

WELLS' ALGOL VARIABLE.

A MINIMUM of the Algol star, *B. D.*$+17^\circ$ 4367, occurred, as predicted in *Circular No. 4*, on the afternoon of January 5, 1896. Through the courtesy of Professor Young, observations were obtained t Princeton by Professor Taylor Reed, with the 23-inch equatorial. t was also observed by Mr. W. M. Reed at Andover. Preparations had been made at this Observatory to obtain a series of photographic mages of it automatically, each having an exposure of five minutes, to observe it photometrically with the 15-inch equatorial, and also visually with the 12 and 6-inch equatorials. Unfortunately, owing to clouds, ew observations were obtained, but these serve to show that the star was faint and diminishing in brightness as expected. Similar preparations were made for the next minimum, January 10, but again clouds prevented observation.

The observations so far obtained show that its time of minimum, uncorrected for the velocity of light, can be closely represented by the formula *J. D.* $2412002.500 + 4.8064\,E$. The uncertainty in the period does not exceed a few seconds, and will probably be known within a single second as soon as the form of light curve is determined. For nearly two hours before and after the minimum it is fainter than the twelfth magnitude. It is impossible, at present, to say how much fainter it becomes or whether it disappears entirely. It increases at first very rapidly and then more slowly, attaining its full brightness, magnitude 9.5, about five hours after the minimum. One hundred and thirty photographs indicate that, during the four days between the successive minima, it does not vary more than a few hundredths of a magnitude. The variation may be explained by assuming that the star revolves around a comparatively dark body and is totally eclipsed by it for two or three hours, the light at minimum, if any, being entirely that of the dark body. The conditions resemble those of U Cephei, which appears to be totally eclipsed by a relatively dark body two and a half magnitudes fainter than itself, but having a diameter at least one half greater. The variation in light of *B. D.* $+17°$ 4367 is more rapid than that of any other star hitherto discovered, and as its range is greater than that of any known star of the Algol type, its form of light curve can be determined with corresponding accuracy. U Cephei is second in both these respects.

THE NEW STAR IN CENTAURUS.

In *Circular No. 4*, insert "it" before "follows" in the ninth line. This word was given correctly in the printer's copy, but was omitted in setting the type. The correction was telegraphed to those astronomers who, it was expected, would use it.[1] The Nova follows the nebula *N. G. C.* 5253, and is north of it. The nebula is assumed to be *C. DM.* $-31°$ 10536, mag. 9.5, with which it was originally identified. As seen with a low power the nebula cannot readily be distinguished from a star. Its magnitude on the Cordoba scale by comparison with adjacent stars was estimated by Mr. Wendell as 9.7, and it could hardly have been overlooked in preparing the Cordoba Durchmusterung, in which many adjacent fainter stars are given. The new star could not have been observed at Cordoba unless we assume, first, that it was bright at that time, although invariably too faint to be photographed on fifty nights distributed over six years, and secondly, that the nebula was overlooked at Cordoba while observing fainter objects in the same region. Even if we make these assumptions, the new star still falls in the same class as T Coronae, which was observed in the northern Durchmusterung several years preceding its appearance as a new star.

The various positions of *N. G. C.* 5253 for 1875 are as follows:

Dreyer's New General Catalogue	R. A. $=13^h\ 32^m\ 51^s$	Dec. $=-31°\ 0'.2$
Cordoba Durchmusterung	R. A. $=13^h\ 32^m\ 49^s.6$	Dec. $=-31°\ 0'.3$
Plate B 13965	R. A. $=13^h\ 32^m\ 50^s.2$	Dec. $=-31°\ 0'\ 23''$
Plate B 14072	R. A. $=13^h\ 32^m\ 50^s.0$	Dec. $=-31°\ 0'\ 21''$

The positions of the Nova derived from these plates differ from each other by only $0^s.1$ in right ascension and $1''$ in declination. The mean position for 1875 is R. A $= 13^h\ 32^m\ 51^s.8$, Dec. $= -30°\ 59'\ 58''$. It will be noticed that according to these measures, the Nova follows *N. G. C.* 5253 by $1^s.7$, and is $24''$ north.

EDWARD C. PICKERING.

January 31, 1896.

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[1] The wording of the *Circular* in this JOURNAL was correct.

YERKES OBSERVATORY—WILLIAMS BAY, WIS.

YERKES OBSERVATORY, UNIVERSITY OF CHICAGO.

BULLETIN NO. 1.

THE present is the first of a series of *Bulletins* which will be printed at irregular intervals by the Yerkes Observatory for the purpose of making announcements which require immediate or special publication. These will include statements with regard to the work of the Observatory, brief descriptions of new buildings and instruments, and other notes on miscellaneous matters of interest. The *Bulletins* will be published in the *Astrophysical Journal.* They will also be distributed separately, without charge, to a limited number of scientific men and institutions likely to find them of service in connection with their work.

ORGANIZATION OF THE YERKES OBSERVATORY.

GEORGE E. HALE,	*Director.*
S. W. BURNHAM,	*Astronomer.*
E. E. BARNARD,	*Astronomer.*
F. L. O. WADSWORTH,	*Astrophysicist.*
[1] T. J. J. SEE,	*Instructor at The University.*
[1] KURT LAVES,	*Assistant at The University.*
FERDINAND ELLERMAN,	*Assistant.*
G. WILLIS RITCHEY,	*Optician.*
EDMUND KANDLER,	*Mechanician.*
WILLIAM GAERTNER,	*Mechanician.*

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[1] Messrs. See and Laves will give undergraduate and graduate instruction in theoretical and practical astronomy at The University in Chicago, and superintend the Student's Observatory, which will be equipped for instruction in practical astronomy preparatory to work at the Yerkes Observatory. For a full statement of the courses of instruction offered at The University and the Yerkes Observatory see the *Annual Register* of The University of Chicago.

BUILDING AND INSTRUMENTS.

The Yerkes Observatory was founded in 1892 through the munificence of Mr. Charles T. Yerkes, of Chicago. In that year Mr. Alvan G. Clark undertook the construction of an object glass of forty inches aperture for the principal telescope of the Observatory, and Messrs. Warner & Swasey were given a contract for the equatorial mounting. The latter was completed in the following year, and exhibited by its makers at the Columbian Exposition. It is similar to the mounting of the 36-inch Lick telescope, but is heavier and more rigid, and many improvements have been introduced. An important feature, long ago suggested by Grubb and others, but apparently employed for the first time in this telescope, is a system of electric motors, by means of which the various motions, etc., are effected. The object-glass has recently been tested by Professor James E. Keeler, who acted at the request of the Director as the "expert agent" called for by the contract. The definition was found to be fully equal to that of the Lick telescope, while the light-gathering power is considerably greater. (See *Astrophysical Journal*, 3, 154, 1896.)

The attachments of the Yerkes telescope will include:

1. A position micrometer by Warner & Swasey.
2. A solar spectrograph, for micrometrical and photographic investigations of the spectra of solar phenomena.
3. A spectroheliograph, for photographing the solar chromosphere, prominences and faculæ by monochromatic light.
4. A stellar spectrograph, for researches on the spectra and motions of stars, nebulæ, comets and planets.
5. A photoheliograph of great focal length, for photographing the direct solar image on a large scale.

The construction of the main building of the Observatory was begun in April 1895. After many delays, it is now under roof, and will be completed in the summer of 1896. Its form is that of a Roman cross, with three domes and a meridian room at the extremities. The principal axis of the building (about 330 feet long) lies east and west, with the dome for the 40-inch telescope at the western end. This dome, which will soon be erected by Messrs. Warner & Swasey, is 90 feet in diameter, allowing ample space for the tube of the great telescope, which, with its attachments, is about 75 feet long. The elevating floor of the observing room is 75 feet in diameter, and will be movable through a range of 22 feet, by means of electric motors.

Of the two smaller domes, the one to the northwest will contain the 12-inch telescope now at the Kenwood Observatory, and the other a 24-inch reflector. Between these domes is the heliostat room, 100 feet long and 12 feet wide. A heliostat with 24-inch plane mirror will stand on a pier at the north end of the room, under an iron roof which can be rolled away to the south.

The meridian room has double sheet-iron walls, with an intervening air space. It is designed to contain a meridian circle of large aperture, but for the present a transit instrument will suffice for the purposes of the Observatory.

The body of the building is divided through the center by a hallway extending from the meridian room to the great tower. On either side are offices and computing rooms, a library, lecture room, two spectroscopic laboratories, dark room, developing room, galvanometer room, chemical laboratory, instrument rooms, etc. In the basement is a large photographic dark room, an enlarging room, concave grating room with large concave grating spectroscope, emulsion room, constant-temperature room, physical laboratory and optician's room. The engines, dynamos and boilers for supplying power and heat are to be at a distance of several hundred feet from the Observatory.

OPTICAL LABORATORY AND INSTRUMENT SHOP.

One novel feature in connection with the Observatory will be its instrument shop and optical laboratory, where it is hoped that it will ultimately be possible to construct the greater part of the instruments and laboratory apparatus which will be needed for purposes of investigation. This work is undertaken not because of any lack of instrument makers in this country, but because it is believed that the best results can only be secured when instruments of research are constructed under the immediate supervision of those who are to use them. Desirable changes in construction or design which become evident as the work progresses can, under these circumstances, be more readily and inexpensively made than when the work is being done at a distance. In the end the instrument makers themselves cannot fail to benefit by the experiments thus undertaken and the types of apparatus evolved. Mr. G. Willis Ritchey has been placed in charge of the optical work. His equipment will consist of a large laboratory fitted with grinding and polishing apparatus, with complete arrangements for testing optical surfaces. The instrument shop, which will be used by Messrs.

Kandler and Gaertner, under the direction of Professor Wadsworth, will be equipped with a complete outfit of instrument-makers' tools.

SITE.

The Observatory is situated about a mile from the town of Williams Bay, near Lake Geneva, Wisconsin, in an ideal rural region, free from the dust and smoke of cities, and removed from the tremors of railroad traffic. Lake Geneva is about seventy-five miles from Chicago, and is reached by a branch of the Northwestern railroad. The site of the Observatory includes about fifty acres of wooded land fronting on the lake. It is believed that the conditions will be favorable for the most delicate investigations in all branches of astronomy and astrophysics.

PUBLICATIONS.

The publications of the Observatory will include: *Bulletins of the Yerkes Observatory*, containing announcements of results, brief descriptions of new buildings and instruments, and notes on the work of the Observatory; *Contributions from the Yerkes Observatory*, consisting of papers contributed to various astronomical and astrophysical journals and the proceedings of scientific societies; *Annals of the Yerkes Observatory*, in the form of quarto volumes containing detailed accounts of special researches; and the *Astrophysical Journal*, an International Review of Spectroscopy and Astronomical Physics, edited by Professor George E. Hale, Director of the Yerkes Observatory, and Professor James E. Keeler, Director of the Allegheny Observatory, with the coöperation of a board of assistant and associate editors.

LIBRARY AND MUSEUM.

It is intended to establish at the Yerkes Observatory a museum for the preservation and exhibition of photographs, charts and drawings of the Sun, Moon, planets, comets, meteors, stars and nebulæ and their spectra, and of optical phenomena observed in the laboratory; photographs and drawings of astronomical and physical instruments; and portraits of astronomers, astrophysicists and physicists.

Scientific men, learned societies and directors of laboratories and observatories are earnestly requested to assist in the formation of a library for the Observatory by contributing to it copies of their publications. Photographs of scientific subjects, on glass or paper, will be very welcome for exhibition in the museum. Drawings and catalogues of scientific instruments are also desired. It is expected that the Observatory will ultimately be able to make some return for such contributions in the form of its own publications and photographic results.

For the present, and until notice of removal to Lake Geneva has been published, packages intended for the Yerkes Observatory should be addressed to the *Kenwood Observatory*, *Chicago*, *U. S. A.* Large parcels may be sent through the agency of the International Bureau of Exchanges of the Smithsonian Institution, to which the Yerkes Observatory is already indebted for such service.

ACKNOWLEDGMENTS.

The present opportunity is taken to extend the cordial thanks of the Observatory to all who have favored it with gifts. Among those calling for special mention are the following:

The large and valuable collection of astronomical photographs exhibited by the Royal Astronomical Society at the Columbian Exposition in 1893; presented by the Society.

A collection of fifty positives on glass, from Professor Barnard's remarkable negatives of the Milky Way, nebulæ and comets; presented by Professor E. E. Barnard.

Eighty-seven bound volumes of astronomical and meteorological observations, including a complete set of the *Memorie della Società degli Spettroscopisti Italiani;* presented by Professor P. Tacchini.

Sixty-eight bound quarto volumes, including *Greenwich Observations* and *Photographic and Spectroscopic Results;* presented by W. H. M. Christie, Esq., Astronomer Royal.

Twenty-two bound quarto volumes of *Cambridge Observations;* presented by Sir Robert S. Ball, Lowndean Professor at Cambridge.

Thirty-nine quarto volumes of the *Annals of Harvard College Observatory;* presented by Professor E. C. Pickering, Director.

On the completion of the Yerkes Observatory the instruments of the Kenwood Observatory will be removed to Lake Geneva, and the existence of the latter institution will cease. To all who have enriched its library by contributions of their publications, grateful thanks are extended.

GEORGE E. HALE.

CHICAGO, February 10, 1896.

ON A NEW METHOD OF PREPARING PLATES SENSITIVE TO THE ULTRA-VIOLET RAYS.[1]

IT frequently happens that for various experimental purposes plates with a sensitive surface of pure silver bromide, or bromo-iodide, are required and are not always easy to prepare. Some few years ago Herr V. Schumann reported that he had found a means of preparing plates sensitive to the ultra-violet rays in regions hitherto quite unrecorded by photography. The full details of Herr Schumann's method of preparing these plates have how appeared in the Transactions of the Vienna Academy of Sciences, and present so many points of interest and show such thorough working out by Herr Schumann that a translation of the paper seemed desirable. It was intended originally to be merely an abstract for my own use, but it was found very difficult to condense it without loss. The paper forms the sequel of two papers on the "Photography of the Rays of Shortest Wave-Length," published in the same volume of the *Sitzungsberichte* (pages 415–475 and 625–694), which deal with the instruments and the necessary optical and electrical arrangements for taking these photographs of the region of the spectrum between λ2313.5 and λ1000, and the many difficulties to be surmounted in doing so, especially in the case of the wave-lengths between λ1820 and λ1000, for which entirely special arrangements had to be adopted.—J. W.

INTRODUCTION.

In my previous papers (noted above) I have followed out the spectrum of electric discharges far beyond the hitherto known limits of the ultra-violet (λ1852), up to the neighborhood of wave-length 1000. The observations were carried out by photographic methods as far as λ1820, with gelatino-bromide plates, and thence to λ1000, with a plate which I prepared specially for this purpose by a new method.

The rays beyond λ1820 have remained quite inactive by any method of spectroscopic observation hitherto employed. They are only perceptible with the above-mentioned plates, with lenses and prisms of fluor spar, and with the spectroscopic apparatus in a vacuum.

The method of preparation of these plates is the result of a research not yet finished, which I only notice briefly in the first part of the papers mentioned. It yields a coating for the plates of the desired fineness and sensitiveness, films which are more sensitive for the new rays than for the remaining part of the spectrum, and which, on this account, as I shall show later on, fulfil their purpose in two ways.

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[1] Translated from the *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften*, Math.-Naturwiss. Classe. Band CII., Heft. VIII., Wien, October 1893, pp. 994–1024. Communicated by COL. J. WATERHOUSE.

The plates are less satisfactory in other respects: they suffer in time from large and small defects in the surface, which can only be checked by proper exposure and by skillful application of definite precautionary measures for the development of the image. But as soon as this precaution is put aside numberless spots appear of different intensity and size, which overrun the image and destroy its otherwise remarkable sharpness. This is the direction in which my process requires improvement, and is, at the same time, the principal reason why I have not published it earlier. I certainly hope still to be able to overcome this defect, as a result of further researches, if more time is available to me for them, as my earlier observations lead me to believe this to be possible.

Under such circumstances it might have happened that the free publication of my process, which I had not intended until this improvement had been made, would have been indefinitely postponed, but this would not have agreed with the final object of my investigations, which was to make the spectroscopy of the new region of rays accessible as soon as possible.

The following circumstances have also influenced me: The above mentioned account of my researches on the shortest wave-lengths has met with such a friendly reception that a more active interest in the investigation of the new region of rays seems to have already been secured. This is shown especially by the efforts that are being directed to the problem of extending our knowledge of the molecular theory by means of the spectrum. It may be remarked thereon, that the earlier researches in this direction, which first of all only aimed at the discovery of a regular connection between the lines of an element and between the spectra of different elements have, up to the present time, given the most favorable results the nearer they have approached the hitherto known boundaries of the ultra-violet region. The shorter the wave-lengths of the region under observation were, so much the more markedly this regularity was disclosed. From this it may be expected that the new region of rays, with its incomparably shorter wave-lengths, will yield rich material for observation towards the completion, as well as for the verification of the results hitherto obtained ; and so much the more that the investigation of a whole series of elements, which has hitherto been quite without result in the direction mentioned, is directed on this part of the spectrum alone. For observations of this kind the new plates, even before their improvement, should be a welcome help. It is this especially which has, in the first place, decided me to abandon my original intention and publish my process at once.

The following paper treats of my own personal labors. These include a series of researches which, in consequence of the not inconsiderable difficulties which were caused at first by the necessity for taking these pictures of the spectrum in a vacuum, have occasioned great expenditure of time and trouble. I have therefore contented myself with single trials of the respective experiments in cases where the verifying of the first results seemed to me superfluous. These results are naturally of inferior value, and it might, perhaps, have been better if I had passed them over in silence. My paper would then have been so incomplete that their admission into it seemed to me to be the lesser of two evils. I shall, however, suitably note them in what follows, so that the possibly doubtful worth of one or the other of them may not influence the principal results of the investigation.

SPECTROGRAPHIC PREPARATORY WORK.

The spectrum in the ultra-violet was already known as far as λ1852. In 1890 I succeeded in discovering waves of shorter length as far as λ1820 by means of photography. Beyond this the photographic plates failed ; whether from want of sensitiveness or from the insufficient energy of the source of light, nothing further could be determined. The only possibility of obtaining an elucidation of this point lay in the measurement of the transparency to light of the different components of the sensitive coating of the plates. I used for this purpose gelatine dry plates containing gelatine and silver bromide.

Dry gelatine, as I was the first to show,[1] absorbs the ultra-violet rays very powerfully, and the more so in proportion to their refrangibility. A film only $0^{mm}.00004$ thick is sufficient to weaken very sensibly rays of about λ1852.

The coating of a gelatine dry plate is at least 500 times thicker. Consequently, waves of shorter length have not the power of penetrating the sensitive depths of such a film, nor of reducing a sufficient quan-

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[1] See vol. cii. part 2, 1893, pp. 457–464.

y of silver haloid to give a dense image. From this it may be con-
uded that the gelatine was not without a share in the loss of intensity
my pictures of the spectrum, and that a film of pure silver bromide
ight have given a better effect.

Pure silver bromide also stops the rays of light energetically; how-
er, according to my photographs, it is rather more transparent for
e wave-lengths 2100 to 1850 than for the rest of the spectrum.
is slight difference was practically of little importance. Of much
ore importance was the extent of the extinction which might result
oto-chemically or photo-thermically. The absorption spectrum
iled to elucidate this point. The photographic behavior of pure
lver bromide could alone decide it.

With this object I coated a glass plate with a thin film of silver
omide, which had been precipitated with an excess of alkaline bro-
ide, dried it, and with it took a photograph of the spectrum of the
ark between two aluminium wires, using a quartz prism and lenses.
he plate was developed like a gelatine dry plate, with pyrogallic acid,
da and potassium bromide. The thickly fogged plate showed a con-
nuous spectrum which extended as far as λ 1820, in undiminished
tensity, as a deep black band of action, bordered all round by a light
dge. The continuity of this band was entirely owing to the spread-
g of all the lines together, an appearance which also occurs with
elatine plates of much higher sensitiveness.

From this negative I concluded that the modification of silver bro-
ide in gelatine emulsion is not wanting in any way in sensitiveness
r the most refrangible rays, nor these in photo-chemical energy, but
ther that the want of sensitiveness of silver bromide in gelatine was
consequence of the weakening of the rays which these suffer on their
ssage to the silver bromide through the gelatine. Hence, it was to
expected that the sensitiveness of silver bromide plates could be
creased by diminishing the quantity of gelatine, by substituting some
ore transparent binding medium for the gelatine, or, finally, by doing
ay with the binding material. This would only answer for the
lected region of observation which ends with λ 1820. I therefore
peated these experiments for the more strongly refracted region
ing near, taking care, however, to reduce the air-space between the
urce of light and the plate, which I had already previously recog-
ized as an important absorbent for short waves of light, to a layer of
nly a few millimeters thickness. In this way it was proved that a

region rich in rays existed beyond λ 1820, and also that for photographing this pure silver bromide is sufficiently sensitive.

These photographs on pure silver bromide form the basis for the preparation of my plates sensitive to the ultra-violet rays, which is treated in the following section of this paper.

PREPARATION OF PLATES SENSITIVE TO THE ULTRA-VIOLET RAYS.

This was tried in three ways: by coating with emulsion, by bathing in silver nitrate and potassium bromide solutions, and by coating with precipitated silver bromide.

A. By Coating with Emulsions.—My endeavors to obtain an ultra-violet sensitive plate with emulsions of silver bromide have given no practical results. They are mentioned only for the sake of completeness.

I hoped, with a silver bromide emulsion containing two to three times as much silver bromide as usual, to obtain a coating poor in gelatine which would have allowed the rays to penetrate to a greater depth and given a more intense picture than is possible with ordinary silver bromide in gelatine. I obtained, however, the exact reverse of this. The silver bromide settled regularly at the bottom, even before the poured out emulsion was set, so that the uppermost surface of the coating of the plate, which in this case is alone of service, consisted merely of gelatine. Plates of this kind were, from the reasons already explained, more insensitive for the most refrangible rays than ordinary dry plates.

An attempt to replace gelatine by agar-agar was still more unsuccessful: the coating of the plate separated, as soon as it was set, into particles of varying sizes, an appearance which had already, some years before, prevented me from using agar-agar for emulsion purposes.

B. By Immersion in Silver Nitrate and Potassium Bromide Solutions.—If a plate coated with gelatine is dipped in a solution of silver nitrate and then in a solution of potassium bromide, a coating of silver bromide is obtained, of which the outer surface is formed of silver bromide without any gelatine. When such a plate is exposed to light the rays first pass through the silver bromide free from gelatine, and then through that which is enclosed in gelatine. From this film of silver bromide free of gelatine, I anticipated good results in photographing the smallest wave-lengths.

If a glass plate be laid at the bottom of the settling vessel, the silver bromide falls on it in a layer of even thickness, and after the supernatant fluid has been syphoned off, dries in a short time to a dull yellowish coating, consisting of pure silver bromide with a small mixture of the salts dissolved in the supernatant fluid (KNO_3 and KBr), which can be removed by washing. Such plates stand development, and also, to a certain extent, the fixing, without injury.

The above is a rough outline of the method I have used for years for preparing plates which have enabled me to find the limits of the spectrum between wave-lengths 1820 and 1000.

V. SCHUMANN.

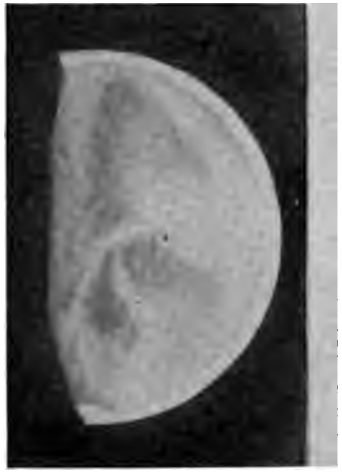
(To be continued.)

PROFESSOR MASCARI'S OBSERVATIONS OF VENUS.

THE three drawings reproduced in the accompanying plate were made by Professor Mascari of the Astrophysical Observatory of Catania, who has given much attention to the observation of Venus at Catania as well as at the Observatory on Mount Etna (altitude 2942^m). The drawing of 1892, October 13, was made under the best observing conditions, when the markings were exceptionally well defined. The dark line in the southern hemisphere, of broken and irregular form, was remarkably sharp, and the gray patches were clearly seen, though in the northern hemisphere they were somewhat diffuse. The observation of 1892, October 12, was made under less favorable conditions, and the image was unsteady. In that of 1895, December 11, the dark patches were distinguishable with difficulty, but their appearance was such as to leave no doubt of their reality. On December 14, at 11^h 25^m civil time, the same dark patches seen at 5^h A.M., December 11, were observed with certainty. In all of these observations, each occupying nearly two hours, the aspect of the planet was the same. It is evident that if the rotation period were 24^h a decided displacement of the dark markings must take place within an interval of 2^h. No such change was noticed, nor could any be detected in observations made before conjunction. It therefore seems to follow that the 24^h period should be rejected in favor of the long period of Schiaparelli. Observations recently made at Rome by Professor Tacchini also confirm Schiaparelli's conclusions.

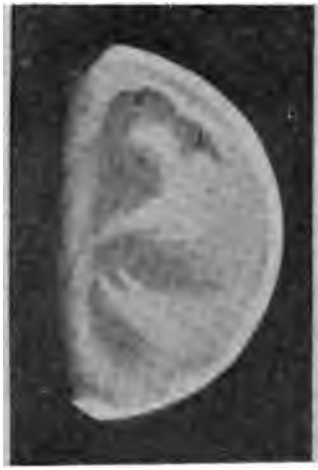
PLATE XVIII.

Fig. 1.



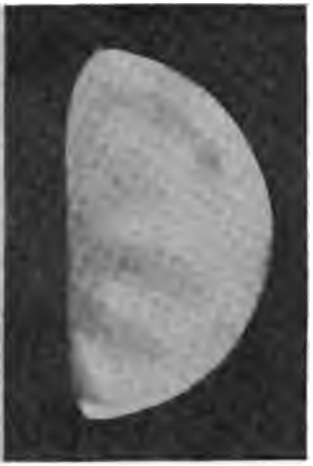
October 12, 1892
$5^h\ 25^m$ to $6^h\ 32^m$ Catania C. T.

Fig. 2.



October 13, 1892
$5^h\ 54^m$ to $7^h\ 9^m$ Catania C. T.

Fig. 3.



December 11, 1895
5^h to $7^h\ 5^m$ Catania C. T.

DRAWINGS OF VENUS BY PROFESSOR A. MASCARI.

THE SHORT PERIOD VARIABLE δ CEPHEI.

IN the November number of THE ASTROPHYSICAL JOURNAL Mr. Alexander W. Roberts, of Lovedale, South Africa, writing upon "Close Binary Systems and their Relation to Short Period Variations," after, in the first instance, "accepting with confidence" M. Bélopolsky's elements, save one, that of inclination, 90°, obtained for the variable δ Cephei (presumably those contained in the February number of THE ASTROPHYSICAL JOURNAL, p. 160, translated from *A. N.* 3257, and which are deduced from 34 spectrograms), and then, later on, suggesting a speculative alteration of Bélopolsky's epoch of minimum brightness so as to harmonize with his own induced theory advanced in this article, suggests a condition for the system of δ Cephei comprising two bright stars, a primary of 5.0 mag. possessing great heat-dispensing power which the companion star, between 7 and 8 mag., is capable of absorbing on its approach and arrival at periastron, its lustre thereby being increased to nearly 5.0 mag., while the pair would then yield a combined light equal to 4.2 mag., leaving over 0.5 mag. of its maximum brightness still unaccounted for. Now this theory, or some modification thereof, might possibly be advanced to explain the constant variations of this star, had the result of M. Bélopolsky's spectrographic investigations been arrived at by an observed alternate separation and closing up of two sets of lines, as in the case of a system consisting of bright components, and not, as it actually was in the case of δ Cephei, by an observed swinging to and fro of a single set of lines revealed by the aid of plates impressed with the spectra of iron and hydrogen. The interpretation of these investigations, I understood, was that the star circulated around a dark body, hence a *cool* or comparatively cool body, and one therefore incapable of increasing the brilliancy of its luminous companion, either by adding to its temperature or combining with its light as required by the Roberts theory. In this star, according to Bélopolsky, minimum preceded the cessation of spectroscopic recession in the line of sight by one day, so that an eclipse interpretation is not possible. Might not, however, tidal disturbances and *bodily* tides in the bright member excited upon its closer approach to the ruling dark body at and near periastron, explain the star's rapid rise in brilliancy, and its periodic variability? This tidal disturbance would not attain its maximum effect until some time after the luminous member had made its nearest approach to the disturbing body. May not also the great eccentricity of this and most other stellar orbits be attributed to the effect of tidal friction ? Perhaps Dr. T. J. J. See, the eminent author of that brilliant paper on "Evolution of the Double Star Systems," read before the Chicago Academy of Sciences, February 7, 1893, and published in *Astronomy and Astro-Physics*, April 1893, may be willing to formulate a theory that will harmonize strictly with all the elements deduced from these, or that may be deduced from any later spectrograms that have been secured by M. Bélopolsky or other skillful observers, whether of δ Cephei or of any of the other members of this class of short period variables.

L. A. EDDIE.

GRAHAMSTOWN, CAPE COLONY,
December 28, 1895.

REVIEWS.

On the Photographic Spectrum of the Great Nebula in Orion. J. NORMAN LOCKYER. *Phil. Trans.* **186**, A, 73–91, 1895.

Although a great amount of work has already been done by spectroscopists on the Orion nebula, many — in fact, most — of the important problems relating to it remain unsolved. In this paper Professor Lockyer, continuing the attack, gives the results of his photographic investigations of the spectrum, and discusses their bearing on the hypothesis of stellar development of which he is the chief advocate. The photographs were all made prior to 1890, and various preliminary notices of the results have already been published.

The instruments employed were a thirty-inch reflector, and a spectroscope with one prism of 60° and two half-prisms of 30°. No further data are given, and in this connection it becomes necessary to refer once more to the old question of the conditions of efficiency in spectroscopes which is brought up by Professor Lockyer, who seems to regard it as an open one, and refers to some passages apparently supporting his own views. It is hardly necessary to say that expressions of individual opinion have no weight in matters that are governed purely by physical laws.[1] The conditions of efficiency of spectroscopes have been very thoroughly worked out in earlier numbers of this JOURNAL.[2]

As for Professor Lockyer's apparatus, we are assured that its dimensions were such that all the light falling on the spectroscope slit was transmitted to the photographic plate. So far this is well; but still other information is required before we can form a fairly correct estimate of the capabilities of the instrument. Whoever has had occasion to consult the older spectroscopic literature, either for purposes of criticism or for his own instruction, must have noticed that the really important data concerning the apparatus are almost always missing; they must be inferred from the results, which thus lose much of their value as a guide to further investigation. At the present time such omissions should not occur. The single statement which conveys the most information about an instrument is that of the resolving power, but since resolving power can be obtained in different ways, which practically are not quite equivalent, particularly when photographic methods are used, it is greatly to be desired that all future accounts of spectroscopic investigations should contain the following data: (1) the focal length and aperture of the large telescope; (2) the focal length and aperture of the collimator; (3) the dimensions, kind and number of prisms; (4) the focal length and aperture of the camera, or in the case of visual observations, the aperture and magnifying power of the observing telescope. Some of these data would be superfluous if spectroscopes were always properly constructed, but an examination of old instruments, and even of some comparatively modern ones, shows that this is by no means the case. Moreover, if an instrument is properly constructed there is no harm in giving the reader data by which he may assure himself of the fact.

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[1] To prevent misunderstanding it may be well to point out that the remarks by Professor Campbell which are referred to apply only to the intensity of the images of bright lines on the photographic plate; the linear separation of the images is left out of consideration, the question being merely one of recording faint lines.

[2] See particularly the article by Professor Wadsworth, *Ap. J.* 1, 52, 1895.

Judging by results, Professor Lockyer's apparatus was at least well adapted to the recording of faint bright lines. The table of fifty-four lines in the spectrum of the Orion nebula is the most extensive that has been published, and its value is not affected by any conclusions that may be based on it. The wave-lengths, however, are rather rough approximations, as one would expect from the method by which they were determined and from the evidently small scale of the photographs. Many of the lines in the table can now easily be identified with the lines of helium, the complete spectrum of which has become known since the memoir was written, and a comparison with Runge's wave-lengths shows that the wave-lengths in the table are frequently in error by two, and occasionally by three-tenth meters. A much higher degree of accuracy than this is required for the certain identification of single unknown lines.

Notwithstanding the existence of these errors, the wave-lengths of all except the brighter lines in the table are more accurate than the best values available seven or eight years ago, and as a result of this narrowing of the limits of uncertainty, origins of the lines which were then considered probable by Mr. Lockyer are now excluded. It is interesting to note how greatly the part has shrunk which lines of the ordinary metals were supposed to play in the production of nebular spectra. Thus, instead of seven lines due to common elements (carbon, magnesium, manganese, iron and lead) out of sixteen recorded nebular lines (three of which are due to hydrogen)[1], we now have only six out of the whole list of fifty-four, for which a similar origin is claimed. Of these six, one is the "magnesium" line at λ 5007; another is the calcium line which is practically coincident with $H\epsilon$, and the existence of which is evidently inferred from the presence of a very faint line at λ 3933 (K?). The remaining four lines are excessively faint, and, in fact, are found only in this table. It is pretty evident that, leaving hydrogen and helium out of consideration, little progress has been made in determining the origin of lines in nebular spectra.

No origin is assigned to the strong line at λ 373, although its connection with the magnesium-flame triplet near the same place is regarded as an open question, to be settled by observations with higher dispersion. Such observations have, however, been made by others. There is no evidence in favor of the supposition that the line is due to magnesium.

In view of recent developments, the helium origin of this line at once suggests itself, but examination shows that it also is not supported by the facts. The wave-lengths which different observers have assigned to the line are as follows: Huggins, 3726; Campbell, 3727; Keeler, 3727; Lockyer, 3729. The nearest helium pair is at λ 3733.01. Lockyer has a nebular line at λ 3707, and there is a helium pair at λ 3705.15; but the nebular line is much fainter than the one at λ 373, while the relative brightness of the helium lines is just the reverse of this.

In the discussion of results the relations existing between the spectrum of the nebula and the spectra of neighboring stars are considered at length. The same subject has been investigated by other observers, and all results agree in demonstrating the closeness of the connection. Other spectral relations, such as those existing between planetary nebulæ and bright-line stars, are also considered with reference to their bearing on the meteoritic hypothesis, and one of the main points of the paper is to show that the relationship indicated between the planetary nebulæ and bright-line stars also holds good for such a nebula as that of Orion. The conclusions would call for more extended notice were it not that they confirm the views which the author had held on the basis of less elaborate investigations, and which are already well known. A figure, illustrating the transition from nebulæ to stars of the highest temperature, according to these views, is given on p. 88.

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[1] *Meteoritic Hypothesis*, p. 290.

Some special features of the observations are to be mentioned. The conclusion that the fainter lines do not have the same brightness relatively to the hydrogen lines in different parts of the nebula agrees with the work of other observers. Dark absorption lines are found in the spectra of the trapezium stars. In the same spectra bright knots occur at the points of intersection with the nebular lines. Taken in connection with the absorption lines just mentioned, this appearance, if due to other than instrumental and photographic causes, would lead to the conclusion, which was rejected by Professor Campbell and the reviewer on the evidence of similar photographs,[1] that the nebular lines in the star spectra are doubly reversed. A distortion of the lines λ 4471 and λ 4495 on one of the plates (illustrated by a figure) would, if real, indicate a motion of 200 miles per second in the line of sight; the possibility that the bending of the lines may be due to a distortion of the film is, however, admitted, and it becomes a very strong probability when we observe that one of these lines belongs to helium, and and that the other helium lines are not affected.

A highly interesting feature of the same photograph is the indication of a reversal of the chief nebular line at λ 5007 in the spectrum of the star Bond 685. It is imperfectly represented in the figure. Unfortunately, the spectrum of this star is shown on only one plate. No reversal of the chief line in the spectrum of Bond 685 could be detected in 1893 by Professor Campbell or the reviewer. J. E. K.

SPECTROSCOPY OF BINARY SYSTEMS.

In recent numbers of the *Astronomische Nachrichten* have appeared, two articles by Dr. T. J. J. See, entitled "Theory of the determination, by means of a single spectroscopic observation, of the absolute dimensions masses and parallaxes of stellar systems whose orbits are known from micrometrical measurement; together with a rigorous method for testing the universality of the law of gravitation" (**139**, 17–26), and "On the theoretical possibility of determining the distances of star clusters and of the Milky Way, and of investigating the structure of the heavens by actual measurement" (**139**, 161–164).

The fundamental principle involved in the proposed method—namely, that when the apparent orbit of a binary system is known, but one linear element is required in order to fix its absolute dimensions, and its parallax—is not new, having been suggested by Fox Talbot in 1871, and since variously applied, directly or inversely, by Niven, Rambaut, Wilsing, and Lehmann-Filhés.

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[1] *A. and A.* **13**, 394, and 493, 1894.

The sight-line component of the orbital velocity is the desired linear element, and this can be accurately determined when the brightness of one of the component stars is sufficient to permit an application of the spectrographic method.

In developing the requisite geometrical formulæ, Dr. See employs the principle of the hodograph, and he gives (perhaps unnecessarily) two proofs of the well-known theorem that the hodograph of the ellipse is a circle whose radius is the quotient of the mass of the attracting body at the focus and the double areal velocity.

The radius-vector (ρ) of the point in the hodograph corresponding to a given point and velocity in the orbit is given by the formula

$$\rho = \frac{\kappa}{\sin \omega \sin i},$$

κ being the linear sight-line component, i being the inclination of the orbit-plane, and ω being the angle between ρ and the ascending node, equal to the angle made by the tangent to the orbit with the line of nodes, and determinate from the anomaly v, and the elements of the apparent orbit.

The radius (α) of the hodograph, which gives its scale, is obtained from the formula $\alpha = \dfrac{\rho}{e \cos \phi \pm \sqrt{1 - e^2 \sin^2 \phi}}$ ϕ being the angle between the tangent and the parameter of the ellipse, and equalling $\frac{v}{2} + \frac{\gamma}{2}$, where $\sin \gamma = \frac{r \sin v}{2a - r}$ and γ is the "anomaly-angle" at the empty focus. The absolute value of the semi-major axis a is found by the formula

$$a = \frac{2 \bar{\rho} \, (t_2 - t_1)}{(r_1 + r_2) \sin (v_2 - v_1)}$$

where t_1 and t_2 are two epochs separated by some convenient interval of time, as a year, "when the companion is near apastron, and the velocity changes slowly," with their corresponding anomalies (v_1, v_2) and radii-vectores (r_1, r_2) and $\bar{\rho}$ is the average velocity (km. per sec.) in the interval, obtained from the hodograph.

The mass of the system in terms of that of the Sun and Earth is found, as usual, on the assumption of the validity of the law of gravitation, by Kepler's harmonic law, and the distance of the system is determined in the usual manner, $\Delta = \frac{a}{\sin a''}$.

The law of gravitation may be tested by the comparison of subsequent spectroscopic observations with the values of κ deduced from the absolute elements of the orbit.

For a dozen binaries with well determined orbits, Dr. See has computed for 1896.5 the velocity in the orbit (ρ) in units of the radius (a) of the hodograph, with the fractional part of this velocity $\left(\frac{\kappa}{\rho}\right)$ which is in the line of sight. For five of these stars, η Cassiopeiae, 9 Argus, α Centauri, Σ 2173, and β Delphini, the conditions are particularly favorable for the determination of κ, on account of its large relative amount, $\frac{\kappa}{\rho}$ being near to unity. For α Centauri and 70 Ophiuchi, the trigonometrically known parallaxes indicate that the sight-line component should amount respectively to 7 and 11^{km} per sec., quantities surely within the range of spectrographic accuracy, provided only that the brightness of the stars is sufficient. Equivalent statistics were given for 1891.0 by Rambaut for forty-five orbits (*M. N.* 50, 307–310, 1890).

Of course the present limitation of all these geometrical applications of the general principle stated by Talbot lies in the insufficiency of our present optical means, or the lack of sensitiveness of our photographic plates. Thus far the sight-line velocity has been spectrographically determined for less than sixty stars. Yet it seems probable that the velocity of at least the brighter component of some of these binaries ought to be within the reach of our largest instruments, and it is to be hoped that the measurement may be undertaken with some of the great refractors already equipped with spectrographs.

Dr. See's second article applies the results of the first to find the distance of star clusters and the Milky Way, on the assumption that binary systems discovered within clusters or the Milky Way are really members of those groups. Common proper motion, magnitude, and spectral type (not a necessary condition) with the stars surrounding the binary would increase the presumption of a common distance, but the results obtained would, of course, be unreliable to the extent of the inaccuracy of the assumption. Even if not at present available, the suggestion may at some time be useful. E. B. F.

The Sun. New and revised edition. CHARLES A. YOUNG. (International Scientific Series. Vol. XXXIV. D. Appleton & Co., New York, 1895.)

The success with which researches in solar physics have been prosecuted since 1881, when this well-known work first appeared, has been recognized in the various subsequent editions by the addition of numerous notes and appendices. The present edition, however, represents a most thorough revision of the text, and the addition of much new matter and many illustrations. In fact, a careful comparison of the text with that of the 1884 edition shows that we are dealing with what is almost a new work, retaining all the excellent qualities which have rendered its predecessor so justly popular, with the added interest of new observational and theoretical results, described without prejudice, and estimated at their true value. Though written for the general reader, to whom it has proved most acceptable, it is safe to say that the book is kept within reach by every astronomer. To illustrate how fully the revised edition represents the present state of our knowledge of the Sun, it will perhaps be profitable to enumerate the principal changes and additions which it embodies. These epitomize the progress of solar research during the last eleven years.

The general remarks which form the introduction to the volume called for no important modifications and remain substantially as they were originally. The value of the solar parallax, with which chapter i. is principally concerned, has undergone no very marked change during the last decade, and the approximate result 8″.80 given in the earlier edition, is retained. (The values adopted by Newcomb and Harkness in their recent volumes of astronomical constants are 8″.797 ± 0.004 and 8″.809 ± 0.006 respectively.) The principal additions to this chapter are an account of the observations of the transit of Venus in 1882, with a cut of the photoheliograph, and a brief description of Gill and Elkins' determination of the solar parallax from heliometric observations of the minor planets. Chapter iii. has been considerably enlarged; it now contains a description of Rowland's gratings, with a cut of the ordinary form of mounting for concave gratings; remarks on spectrum photography and its value for certain classes of work; an excellent cut of the great Princeton spectrograph attached to the 23-inch telescope; descriptions of the spectrum maps of Rowland, Higgs and Langley; Rowland's latest list of the elements present in the reversing layer;

Trowbridge's results with regard to oxygen in the Sun, showing that none of the bright lines in the line spectrum of oxygen occur in the solar spectrum between $\lambda 3750$ and $\lambda 5034$; the spectroscopic investigations of Crew and Dunér on the solar rotation; and Cornu's method of picking out the telluric lines by causing them to vibrate in unison with an oscillating solar image. (It may be noted in passing that the references on p. 64, line 14, should be to pages 74 and 202.)

The chapter on "Sun-spots and the Solar Surface" describes the work of Deslandres and Hale,[1] in photographing the solar surface with the spectroheliograph; corrects the popular belief in a sudden and decided magnetic disturbance precisely coinciding in time with Carrington's unique observation of a brilliant object moving across a Sun-spot; and includes Professor Young's own observations of the bulbous ends of penumbral filaments seen in Sun-spots. His success in resolving the ends of the filaments into fine, sharp-pointed hooks with the 23-inch Princeton refractor, seems to indicate that their ordinary appearance is due to poor "seeing" and insufficient resolving power. A cut of the great Sun-spot of October 1883, from a drawing by Tacchini, appears on p. 128. A discussion of the observations of Howlett and Sidgreaves, whose results oppose those of Wilson and De La Rue, does not lead the author to abandon the long-established idea that spots are depressions in the photosphere. While the painstaking researches of the later investigators are entitled to most respectful consideration, and must be taken into account in all future discussions of the subject, it is probable that to the majority of solar physicists the balance of evidence seems to lie on the side of the older view. The common lack of symmetry in Sun-spots, and the rapidity with which they develop while crossing the disk, render statistical studies of penumbral width somewhat inconclusive, as the conflicting evidence clearly testifies. Although observations of spots at the limb are ordinarily complicated by the presence of an encircling ring of faculæ, they may be said to favor, rather than to oppose, the original idea of Wilson. It may be that micrometrical measures of the apparent width of the penumbra may ultimately assist in deciding the matter.

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[1] One passage here, which entirely misrepresents my views, cannot be allowed to pass without correction. It reads as follows: "This makes it more or less probable that the faculæ, instead of being mere protrusions from the photosphere, are really luminous masses of calcium vapor floating in the solar atmosphere,—possibly as Professor Hale thinks, identical with the prominences themselves. But Deslandres and Maunder dissent from this, and say that while these objects shown by the spectroscope are clearly connected with the prominences, they are as clearly not identical with them." As a matter of fact, I have always considered the combined evidence to indicate that the brighter reversed regions represent the hot calcium vapor, rising from the Sun's interior through the faculæ, and distributed throughout their upper portion. In certain exceptional cases, to some of which I have called attention, bright eruptive prominences on the disk may be photographed. M. Deslandres now holds that the spectroheliograph shows the calcium vapor in the chromosphere above the faculae, but not in the faculæ themselves. The question at issue is simply this: At what height above the photosphere do the bright reversals originate? M. Deslandres' earlier view was as follows: "Cependant les flammes faculaires sont formées de calcium et d'hydrogène; elles ont le même composition que les protubérances; ce sont des protubérances se projetant sur le disque."—*Knowledge*, December 1893.

The period of the Sun's axial rotation deduced by Hornstein, Bigelow and Veeder from periodic variations in the Earth's magnetism are given in a new footnote "for what they are worth," the author evidently wishing to see them much more firmly established than they are at present, before incorporating them in the text. The discussion of the important subject of the equatorial acceleration is somewhat augmented, and now includes Wilsing's period deduced from measures of the faculæ recorded on the Potsdam photographs. The fact that these results do not agree with observations of spots and Dunér's spectroscopic measures in establishing a general equatorial acceleration has never been satisfactorily explained, though the necessity of determining the positions of the faculæ from plates which show them only when near the limb, naturally lessens one's confidence in Wilsing's conclusions. The changes in form which ensue during the passage of a facula across the disk are such as to make subsequent identification of the point previously measured practically impossible. Bélopolsky's results (which are not given by Professor Young) appear to him to contradict those of Wilsing, and to give periods corresponding with those of the spots. Wilsing rightly maintains that no very certain inferences can be drawn from the limited number of measures made by Bélopolsky, and concludes from a discussion of the observations that they merely show a constant difference from his own. Bélopolsky replies that they refer to a much higher latitude, and the constant difference pointed out is in very close agreement with the corresponding difference between the rotation periods of spots in the respective zones. Moreover, as Professor Young remarks, Stratanoff's more recent results are in substantial accordance with Carrington's spot period. The question demands a much more extended investigation than it has hitherto received. Other additions to this chapter include a reference to Bélopolsky's application to the Sun of Jukowsky's investigations on the rotation of fluid masses, a cut representing the apparent positions of the solar axis at different times of the year, and a correction to the previous edition regarding Spoerer's views as to the condition of the Sun's interior.

Chapter v., dealing with the periodicity of Sun-spots, their effects upon the Earth, and theories as to their cause and nature, has naturally received much attention in the revision. Wolf's Sun-spot numbers are brought down to 1891. It is fortunate that the continuity of the series, broken by the death of Professor Wolf in 1893, has been restored by his successor, Herr Wolfer. Spoerer's important discovery of the variation of spots in latitude during the eleven-year period is described, and illustrated by curves showing the distribution of the spots in latitude from 1855 to 1880. Dr. Veeder's idea that auroras are the direct result of disturbances at the eastern limb of the Sun does not commend itself to Professor Young, who quotes Maunder's statement that in a period of nearly nineteen years the three greatest magnetic storms have been simultaneous with the maximum development of the three greatest Sun-spots, none of which were near the eastern limb at the time. That in certain cases violent disturbances on the Sun's limb exactly coincide with twitches of the magnetic needle is illustrated by Professor Young's well-known observation of this kind at Mount Sherman in 1872. But equally violent phenomena with no corresponding magnetic perturbations have been far more frequently observed. Our author does not consider the Sun's effect upon terrestrial magnetism to be a direct one—the passage he quotes from Lord Kelvin's 1892 address seems to disprove that; but he does hold that there is a connection of some kind between solar activity and the oscillations of the magnetic needle. In the case of a magnetic storm he considers it not impossible that the Sun expends sufficient energy to "pull the trigger," but not necessarily to produce the explosion. Whence comes the energy represented by the storm itself remains an apparently insoluble mystery.

Wilson's recent measures of the heat radiated from Sun-spots are referred to in connection with those of Langley, and attention is called to the interesting fact that the radiation of the umbra as compared with that of the neighboring photosphere increases as the limb is approached. Among the recent theories of spot formation those of Lockyer, Schaeberle and Oppolzer are given in outline. The two former are in practical agreement with that of Sir John Herschel, in so far as they attribute the genesis of a spot to the fall of heavy masses upon the photosphere,—an idea which can hardly be reconciled with the statements of Secchi, Sidgreaves and others that faculæ sometimes appear upon the disk before the spot has formed. Oppolzer's theory is more favorably criticised, but the difficulty of accounting for the polar streams is pointed out, and it might have been added that as yet we have no substantial observational evidence of their existence.

In passing on to a discussion of the prominences no important changes are introduced until the list of chromospheric lines is reached. In this the lines $\lambda 7065.50$ and f are now ascribed to helium, while H and K, which in the earlier addition were doubtfully credited to hydrogen, are now given to calcium. A woodcut, after an excellent photograph by Professor Reed of the C line doubly reversed in the chromosphere spectrum, is given on p. 209, Trouvelots "dark" prominences and Tacchini's "white" prominences are mentioned in the discussion of the ordinary types, but with the remark "that the evidence hardly warrants confident belief in the existence of such objects." Brester's theory of a quiescent solar atmosphere, with prominence forms produced by the effects of luminescence, is criticised on the ground that it offers no adequate explanation for the line distortions ordinarily attributed to motion in the line of sight. Until it is proved that a flash lighting up a succession of stationary particles can produce the spectroscopic phenomena observed in eruptive prominences, Brester's theory cannot be expected to receive favorable consideration from solar physicists. Schmidt's theory has gained rather wider acceptance, but a closer examination of its consequences is leading some of its former supporters to abandon it, at least in its application to the Sun. Among the numerous objections which have been raised against it, that pointed out by Professor Young is as simple and conclusive as any. A mass of metallic vapors exposed to the cold of space must inevitably form a photosphere within a short time. Permanent gases would not thus condense, and it may therefore be that some of the planetary nebulæ conform to Schmidt's theory.

The remainder of the chapter is devoted to an account of the methods and results of prominence photography, a field in which Professor Young himself was the first to experiment. (On p. 230, line 22, "1884" should be "1889".) The cuts include excellent double reversals of H, K and $H\epsilon$, and prominences photographed in the H, K and $H\alpha$ lines through a wide slit at Princeton; the spectroheliograph used from 1891 to 1895 at the Kenwood Observatory, and three groups of prominences photographed with it. The work of Deslandres and Hale is accurately described, though the spectroheliograph used by the former is much more efficient than that with which he is credited.

Chapter vii. is enriched with three new cuts of the corona, from photographs taken at the eclipses of 1882, 1889 and 1893. (In the title of Fig. 91, "Burckhardt" should be "Burckhalter.") Unfortunately the beautiful detail of Professor Schaeberle's photograph of the inner corona has been lost in the process of reproduction. An account of the unsuccessful attempts of Huggins, Wright and Hale to photograph the corona without an eclipse closes with the assurance that "to the writer at least, the case appears by no means hopeless"—a crumb of comfort that those who are still engaged upon the problem can hardly fail to appreciate. The five pages devoted to theories of the corona include those of Hastings, Schaeberle and Bigelow, with a brief description of the suggestive electrical experiments of Pupin.

The first half of the next chapter, on the Sun's light and heat, remains practically unchanged, and is followed by a revised account of Langley's bolometric work, with cuts of the spectrobolometer and a small map of the infra-red spectrum. The results of Langley, Frost and Wilson, on the radiation of the photosphere at various distances from the center of the disk, are tabulated for convenient comparison. Taken in connection with the earlier photometric measures of Pickering and Vogel, they agree in bringing out very clearly the rapid increase of absorption in the upper spectrum. In the discussion of the effective temperature of the Sun, Rosetti's value of 10000°C. is now supplemented by Le Chatelier's and Wilson and Gray's results of 7600°C. and 8000°C. respectively. Scheiner's conclusion, derived from a study of the relative intensities of two magnesium lines, that the temperature of the reversing layer at the altitude where the magnesium absorption is produced is about equal to that of the electric arc, is also given.

The volume closes with a valuable summary of the observatory and laboratory investigations of helium.

The present review, touching as it does upon only its new features, must fail to convey any sense of the continuity of an exceptionally well-constructed work. Professor Young's well-known clearness of expression and attractive style will recommend the book to every intelligent reader.

G. E. H.

Observations des Protubérances Solaires faites à l'Observatoire d'Odessa. A. KONONOWITSCH, N. ZWIETINOWITSCH, A. ORBINSKIJ. (Odessa, 1895).

The observations contained in this volume were undertaken in 1892 at the suggestion of M. Bredichin, through whose influence a direct vision spectroscope with two prisms was provided for the 6½-inch refractor of the Odessa Observatory. The tabulated results, which cover the period August 1892—August 1893, include (1) Odessa civil time of observation; (2) position angle of center of prominence; (3) length of base in degrees of the solar circumference; (4) height in seconds of arc. Prominences whose spectra contained lines other than the first three of the hydrogen series and D_3 are specially designated. It would appear, however, that attention was confined almost exclusively to observations in the $H\alpha$ line, as in examining other parts of the spectrum the adjustment of the slit in the focal plane of the telescope was left at the position for this line. It is evident that under such circumstances other lines would be seen only at a great disadvantage. The length of prominences along the limb was measured with a filar micrometer, which served also to determine the height of those near the poles. The height of prominences in lower latitudes was deduced from the time of transit across the (tangential) slit. The volume contains a complete series of scale drawings of all prominences seen, the daily observations being platted in parallel strips, showing the solar circumference with the prominences at the measured position angles. No attempt is made to show the structure of the chromosphere. Considering the differences in the instruments employed, and in the times of observation, the drawings show a fairly good agreement with those published in the *Memorie della Società degli Spettroscopisti Italiani.*

G. E. H.

RECENT PUBLICATIONS.

A LIST of the titles of recent publications on astrophysical and allied subjects will be printed in each number of THE ASTROPHYSICAL JOURNAL. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors.

For convenience of reference, the titles are classified in thirteen sections.

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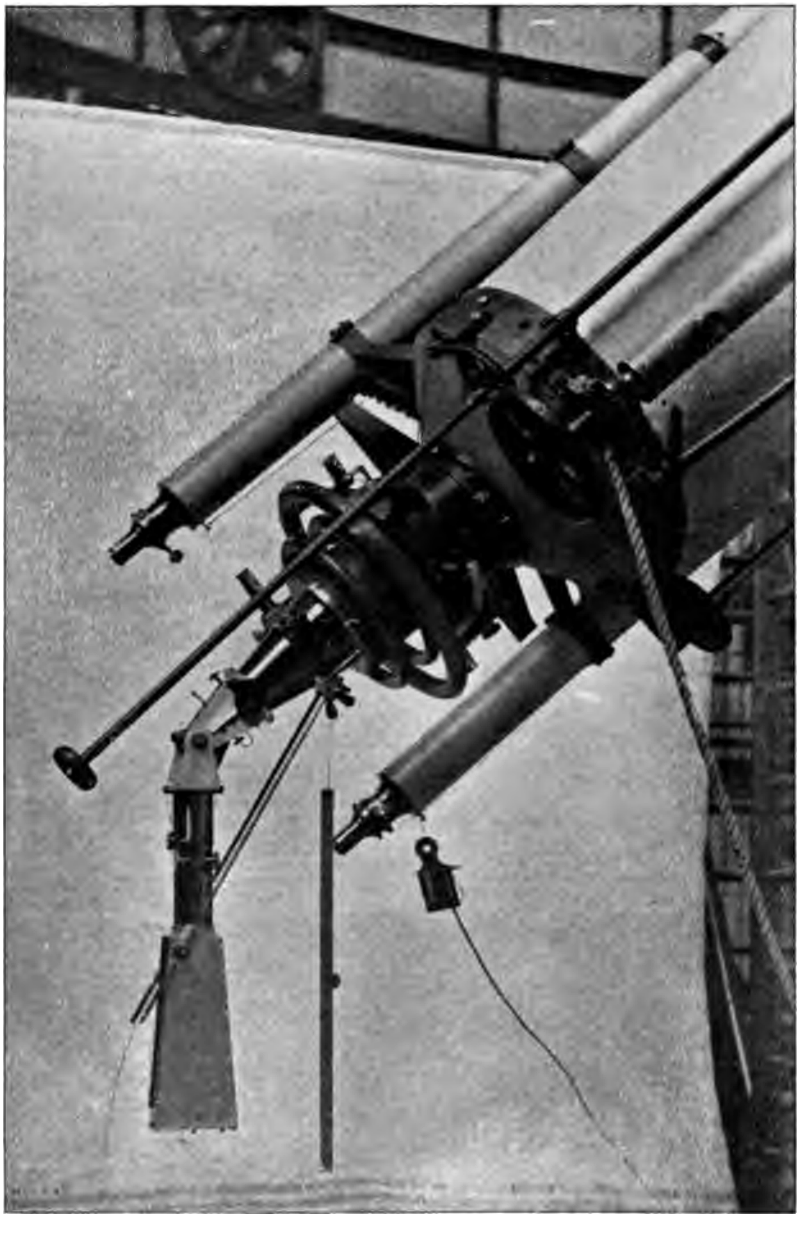
PLATE XIX.



THE EYE-END OF THE NEWALL TELESCOPE WITH THE SPECTROSCOPE ATTACHED.

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ON THE LAW OF THE SUN'S ROTATION.

By J. WILSING.

In the fifty-first volume of the *Memoirs of the Royal Astronomical Society*, Professor Sampson has published a very interesting paper,[1] which is based upon views quite similar to those explained in an earlier paper of my own.[2] As Professor Sampson seems to have been unacquainted with this work of mine, the agreement of the two papers, with respect to their more important conclusions, may fairly be regarded as supporting my views, and therefore I may be permitted to refer to my earlier article in connection with a short discussion of Professor Sampson's work.

The aspect of the irregular gaseous nebulæ, as for example that of the nebula in Orion, shows conclusively that in these objects matter exists neither in a condition of relative equilibrium nor, under conditions permitting motion, in a state of rest. Although changes in the forms of nebulæ have not yet been demonstrated, the explanation of this fact is to be found in the minuteness of the changes relatively to the distance of the object. A more advanced stage of development is met with in the planetary nebulæ, but here also conditions of equilibrium and prohibitive conditions of motion are equally out of the question. The fixed stars, to which class our own Sun belongs, represent a still later phase of celestial evolution. Here we may assume that the surfaces of equal density in the interior of the body approximate to concentric surfaces of revolution, and that radial currents are beginning to disappear. Currents *in* the surfaces of equal density can, on the other hand, still continue, since such currents, when the motion of all the particles in these surfaces is about a common axis, can be destroyed by the action of internal friction only. From this point of view the currents on the solar surface which were discovered by Carrington, and which are characterized by the fact that the angular velocity of the particles varies with their heliocentric latitude, are seen to be a phenomenon organically connected with this particular phase of celestial development. We are therefore relieved from the difficulty of accounting for the maintenance of these currents on mechanical and physical principles, since they appear as the result of earlier conditions of motion.

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[1] "On the Rotation and Mechanical State of the Sun." *Mem. R. A. S.* 51, 123.

[2] "Ueber das Rotationsgesetz der Sonne und über die Periodicität der Sonnenflecke." *A. N.* 3039, 127, 233.

But stationary conditions are as impossible in this case as in the earlier stages of development, as we see on taking into consideration the effect of internal friction. Hence, in order to make intelligible the observed fact that the currents on the Sun's surface undergo no apparent change, we have still to show that, as in the parallel case of the nebulæ, the assumed changes in the present conditions are too small to be perceived in the time covered by our observations, and hence that *practically* the solar currents may be regarded as having stationary forms. In another place I have endeavored to answer the question as to what changes in the existing currents are produced in a given time by the equalizing effect of internal friction. In doing this I have restricted the inquiry to the assumption of constant density of the matter in the currents, an assumption which, if Mariotte's law remains valid, requires a distribution of temperature proportional to the corresponding pressures. Moreover, the forces which determine the pressure at any point have a certain poten-

Observations give the motion at the surface of the Sun,
which the only conclusion that can be drawn with certainty
hat even in the interior of the Sun *differences* of angular
city must exist, at least to a certain depth below the surface.
, since the temperature probably increases with diminishing
nce from the center, and since, according to Maxwell's law,
oefficient of internal friction increases with the temperature,
ifferences of angular velocity above referred to must dimin-
s the center of the Sun is approached, until a surface is
ed, the particles of which rotate with sensibly constant
lar velocity about a common axis.

he problem to be solved was therefore, in its general form,
llows. The central part of the Sun, bounded by a spherical
ce, rotates with practically uniform angular velocity. Far-
toward the surface of the Sun are layers in which the parti-
have *different* angular velocities. The law, according to
h the angular velocity varies along a radius, is unknown.
he surface the velocities of rotation at a given time t must
with observation. Then the equations of motion which
mine the angular velocity must be satisfied under these
itions.

ssuming a constant coefficient of friction, the conditions are
fied by an expression of the form $\omega = a + b \sin^2 \phi$, in which
d b depend only upon the radii R and $R,$ of the surface and
al sphere respectively, and on the time, and contain other-
still undetermined functions, and ϕ is the heliocentric lati-
The form of this expression is, however, precisely that
h Faye has chosen to represent the angular rotation
rved by Carrington. Now, the change which is sought in
ifferential current velocity on the Sun's surface is determined
he change of the coefficient b with the time. The signifi-
e of introducing the undetermined functions above referred
s, that the conditions for the surface are satisfied by an
ite number of solutions. Hence the problem would be a
ectly definite one only in case the motion at time $t = 0$
known for the parts of space in question. But since we are at

present interested in determining only an inferior *limiting* value of the time in which the differential currents change by a definite amount, capable of being detected by observation, a determination of the motion at time $t = 0$, may be adopted if it is certain that the changes in the differences of velocity, which follow as necessary consequences of the determination, are *more rapid* than those which represent the actual facts. This condition is certainly fulfilled if we imagine the region outside the central sphere, in which the different angular velocities are found, to be extended beyond the surface of the Sun, and to be bounded by a spherical surface which, like the inner one, rotates with uniform velocity. The motion, which may be compared to that of a stream flowing between *two* fixed banks, will then be more rapidly destroyed by friction, if there is no exterior force to support it, than it would be if there were only *one* rigid boundary. In accordance with this principle I have computed a numerical example with a given distribution of velocities, and find that changes in the surface currents of the Sun would not become perceptible until after the lapse of millions of years.

In a similar manner Professor Sampson has recognized the importance of internal friction in the problem of explaining the solar rotation on mechanical principles. The problem which he proposes to himself is made somewhat broader by removing the restriction of incompressibility; but the introduction of pressure, density and temperature into the equations with the aid of Mariotte's law necessarily requires a knowledge of the distribution of these three variables in the interior of the Sun. In default of definite points of attack furnished by observation, Mr. Sampson develops an interesting theory, which essentially rests on these two hypothetical laws: "The energy lost in radiation per unit time by a small isolated body of gas is proportional to the temperature and the mass conjointly," and "The energy absorbed per unit time by a small portion of gas is proportional conjointly to the mass of the gas and to the whole energy of the radiations that penetrate it." From these propositions Mr. Sampson deduces the consequence that the density, pressure and temperature, hence also the coefficient of friction, in the body of the Sun, must be sensibly constant, a result which practically follows also from my restriction of the problem to the determination of the motion of an incompressible fluid. In his further treatment of the problem Mr. Sampson defines the required solution of the equations more closely, by the condition that the angular velocities, which must agree with observation at the surface, increase along a radius until the center of the Sun is reached. This special assumption, to which Mr. Sampson has been led by certain experiments of Herr Bélopolsky's,[1] may be harmonized with the views that I have developed above, if the region around the center is left out of consideration. The requirement joined to it by Mr. Sampson can then also be satisfied by the solution that I have given. On the other hand, Mr. Sampson does not investigate the change of the motion with the time. As the rotational motion of the Sun is assumed to be independent of the azimuth, so also is the density, provided that an assumption is granted which I have proved in another place; the assumption, namely, that the changes of motion at a definite point on the Sun's surface which depend upon the time are too small to be detected, even during a period of very great length.

The leading idea in the memoir of Professor Sampson is, without doubt, the same as that which I desired only to shape into a more definite form — that the mechanical conditions of motion, like the physical constitution of the Sun, are to be regarded as transitory, and peculiar to the momentary phase of its development; and as they are the result of earlier conditions of motion, so in the course of time they will be transformed, largely by the effect of friction, into simpler conditions, such as we find in the heavenly bodies that have already become solidified and rigid.

ROYAL ASTROPHYSICAL OBSERVATORY,
Potsdam, January 1896.

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[1] *A. N.* 2954, **124**, 17–22.

By P. TACCHINI.

I TAKE pleasure in sending you the results of our solar observations made during the second half of 1895. The statistics for the spots and faculæ are given in the following table:

1895	Number of days of Observation	Relative Frequency		Relative Areas		Number of Spot Groups per day
		of Spots	of days without Spots	of Spots	of Faculæ	
July	30	12.06	0.00	28.4	78.5	3.9
August	30	22.50	0.00	90.2	75.7	4.4
September	30	11.34	0.00	50.0	70.0	4.1
October	22	15.77	0.00	77.8	76.1	3.7
November	25	10.36	0.04	41.2	66.8	3.7
December	16	10.56	0.00	72.9	67.8	5.8

In comparing these results with those given in my last communication on the observations of the first half of 1895, it is seen that the spots have continued to decrease, with a secondary minimum in November, during which days without spots were first recorded. Attention should also be called to the small area of the spots in July.

For the prominences the following results have been obtained:

1895	Prominences			
	Number of days of Observation	Mean Number	Mean Height	Mean Extent
July	30	7.80	41″.4	2°.0
August	30	7.67	41 .9	1 .8
September	28	5.00	41 .8	1 .9
October	20	4.45	36 .4	1 .7
November	21	5.10	36 .1	1 .8
December	13	5.38	38 .0	2 .0

Thus the prominences have not decreased in harmony with spots; it may be said that the phenomena of the quiescent minences remained practically unchanged during the entire r 1895. It is also evident that the minimum of October was in accord with the spot minimum.

The following tables show the distribution in latitude of the ır phenomena observed during the third and fourth quarters 1895:

THIRD QUARTER, 1895.

titudes	Prominences		Faculæ		Spots	
+80°	0.000	0.577				
+70	0.000					
+60	0.003					
+50	0.024					
+40	0.123		0.000	0.522		
+30	0.112		0.009			
+20	0.126		0.102		0.073	0.500
+10	0.113		0.197		0.305	
0	0.076		0.214		0.122	
-10	0.073	0.423	0.138	0.478	0.183	0.500
-20	0.100		0.201		0.268	
-30	0.084		0.125		0.049	
-40	0.100		0.009			
-50	0.050		0.005			
-60	0.007					
-70	0.004					
-80	0.003					
-90	0.002					

During the third quarter the prominences showed a greater quency in the northern zones than was the case in the two ceding quarters, while in the fourth quarter the difference is ıll, with the balance in favor of the southern hemisphere. phenomena were, however, invariably well developed from equator to ± 50°, as in the two preceding quarters; between se limits and the poles the prominences were few in number.

The faculæ remained in lower latitudes, *i. e.*, between + 40° l — 50°, with maxima of frequency in the zones (0° ± 20°), in the first half of 1895, but their development was greatest in northern hemisphere.

FOURTH QUARTER, 1895.

Latitudes	Prominences		Faculæ		Spots	
90°+80°	0.000	0.485				
80 +70	0.003					
70 +60	0.000					
60 +50	0.007					
50 +40	0.071		0.000	0.516		
40 +30	0.128		0.011			
30 +20	0.117		0.098		0.031	0.570
20 +10	0.099		0.228		0.277	
10 . 0	0.060		0.179		0.262	
0 −10	0.057	0.515	0.141	0.484	0.092	0.430
10 −20	0.135		0.201		0.246	
20 −30	0.124		0.120		0.092	
30 −40	0.089		0.022			
40 −50	0.078		0.000			
50 −60	0.011					
60 −70	0.000					
70 −80	0.014					
80 −90	0.007					

Finally, the spots, as in the first two quarters of the year, did not occur outside of the parallels ± 30°, and had their maxima of frequency in the zones (± 10° ± 20°). Their greatest development was in the northern zones, as in the second quarter. No important metallic eruptions or phenomena in the vicinity of spots were observed.

ROME, January 28, 1896.

THE SPECTRUM OF MARS.

By LEWIS E. JEWELL.

IN the June number of THE ASTROPHYSICAL JOURNAL, Professor W. W. Campbell in his "Review of the Spectroscopic Observations of Mars," criticises the method used by me as less direct and practical than the ordinary telespectroscopic method.

As there seems to be some misunderstanding regarding the methods I used, and their decisive character where questions such as determining the presence or absence of oxygen or water vapor in a planet's atmosphere is concerned, and the resolving power necessary for such purposes, I have thought it best to add a further note upon the subject, being confident that observations with our present instrumental equipments, under the limiting conditions with which we are surrounded, are totally inadequate for the solution of such problems.

For several years I made careful measurements of the intensity of lines in the spectrum of the Earth's atmosphere, which are produced by oxygen and water vapor.[1] The methods used in my measurements were exact enough to determine with certainty whether any given line was due to oxygen or water vapor, by making three or four careful observations from noon until sunset, unless the air was exceptionally dry, as sometimes occurs during a very severe cold wave.

During the investigation the usefulness of instruments of differing resolving powers was carefully determined by making measurements with them under various conditions, therefore the results I gave were the facts of actual observations, checked by observations made at the same time with the most powerful instruments, in the laboratory of the Johns Hopkins University, and were not deductions from theoretical considerations.

It is well known that a dark line must have a certain angular width before it can be seen by the eye. It must also be dark enough to contrast sufficiently with the background. It is also well known that all stars are so remote that any attempt to discern their actual disks will fail however we may increase the magnifying power of our telescopes. Consequently an opera-glass is as useful for the purpose as the largest telescope in existence, and it is useless to either contend that one telescope is better for the purpose than another, or to use our time and energies in trying to see what is unquestionably beyond the powers of our instruments.

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[1] A paper embodying most of the results of this investigation is in process of publication by the U. S. Weather Bureau.

In my paper in THE ASTROPHYSICAL JOURNAL for 1895, I pointed out the fact that the means heretofore used to determine the presence or absence of water vapor in the atmosphere of Mars, were entirely inadequate for the purpose, and nothing could possibly be determined unless the amount of water vapor in its atmosphere were much greater than in that of the Earth.

I showed that with the Steinheil spectroscope, having two 60° prisms, an amount of water vapor could be detected equal to that present in the Earth's atmosphere during October at Baltimore, providing the source of light were as bright as sunlight and no other complications entered into the problem.

It appears from Professor Campbell's paper that he used either a single 60° or 30° prism in his observations, or a resolving power of less than half that of the Steinheil spectroscope, and as his source of light was many thousands of times less bright than sunlight, his resolving power was much less than half, and in addition observations were complicated by viewing Mars through considerable water vapor in the Earth's atmosphere. In fact it is doubtful if he could, under the circumstances, detect with any degree of certainty the presence of water vapor in the atmosphere of Mars, if it were present in as large an amount as in the Earth's atmosphere during July, and the telescopic appearance of Mars does not allow us to expect the presence of anything like such an atmosphere of water vapor.

The determination of this problem being entirely beyond their resources, it seems to me unprofitable to discuss the and August, to be about the same as at Baltimore during May, but subject to fewer fluctuations.

The curve representing the distribution of water vapor at different heights in the atmosphere, varies much less from day to day than Professor Campbell supposes, and is not subject to as great fluctuations as the amount of water vapor determined by surface observations.

Meteorological questions are, however, out of place in this discussion if the means for observation are totally inadequate to settle the main question at issue.

A NEW FORM OF REFRACTOMETER.[1]

By C. PULFRICH.

IN its essential features this apparatus[2] consists of a 90° prism of highly refractive glass, one face of which, turned upward and made horizontal, is brought into contact with the object to be investigated, while through the other (or vertical) face is observed the boundary line limiting the light which, after passing through the object, enters the prism under grazing incidence. From the angle i, at which the limiting ray emerges from the vertical face, and which is measured by means of a telescope and graduated circle, and the known refractive index N of the prism, the refractive index n of the substance under investigation is obtained by means of the formula $n = \sqrt{N^2 - \sin^2 i}$. The index relates to sodium light, which is used as a source, and its value is most conveniently taken from a table.

A short glass cylinder, cemented to the upper face of the prism, serves for the reception of fluids (Fig. 1); light at grazing incidence enters above the cemented joint.

Solid substances (Fig. 2) are provided with two surfaces, I and II, approximately at right angles, of which one (I) must be plane and well polished, while the other (II) need only be polished well enough to transmit light. No definite requirements as to the size of II are set by the method. Objects of any thickness can be investigated, down to that of cover-glasses ($0^{mm}.15$). On the other hand, the edge in which the surfaces I and II intersect must be perfect—a requirement which is most easily met by polishing II on two objects at the same time, their faces I having been previously cemented together.

In the case of a solid object, a thin film of liquid (whose index $n' > n$) is used between its lower surface and the prism.

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[1] Communicated by Carl Zeiss Optical Works, Jena.

[2] A detailed description of method and apparatus will be found in *Z. f. Instrum.* p. 47, 1888; also in *Das Totalreflectometer und das Refractometer für Chemiker, etc.*, C. PULFRICH, Leipzig, 1890, and in different chemical text-books and periodicals.

According to Le Blanc[1] the refractometer can also be used for the measurement of solid bodies in the form of powder, by placing the powder in a fluid which has the same refractive index.

While the instrument as originally constructed was restricted in its use to determinations of refractive indices (n_D) of fluids at the temperature of the room, the form which I have recently given it allows the scope of its application to be greatly extended, so as to include, in fact, almost all quantitative investigations on refraction and dispersion. Among these uses may be mentioned the following:

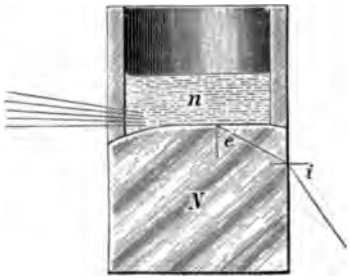

FIG. 1.

1. Measurements of refraction (n_D) and dispersion (difference of indices for the Fraunhofer lines C, D, F, and $H\gamma$) for transparent fluid and solid bodies, either single or double refracting.
2. Investigations of fluids at high temperatures, including bodies that are fluid only under such conditions.
3. Determination of the differences of refractive or dispersive power of such fluid or solid substances as differ but little in their optical properties. The instrument is here used as a ***differential*** refractometer.

In the construction of the accessories which serve for the purposes mentioned above, special attention has been given to securing simplicity in the methods of observing and in the subsequent computations. All parts of the apparatus are, therefore, permanently fixed in position after being once for all properly adjusted, and hence are always ready for use. The computations for dispersion and other differential quantities from the data given by the observation are performed, in quite the same manner as hitherto for n_D, without the use of logarithms, by means of suitable tables.

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[1] *Z. f. Phys. Chem.* p. 433, 1892.

With respect to accuracy, the apparatus is designed to meet the requirements which are usual in spectrometric measurements; *i. e.*, exactness to a single unit of the fourth decimal place in the refractive index, and to one or two units of the fifth decimal place in the dispersion and other quantities depending upon differential measurements.

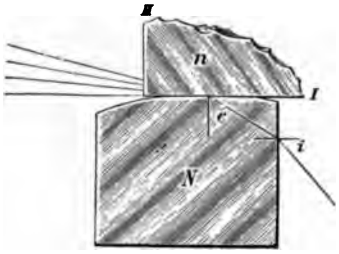

Fig. 2.

In adapting the apparatus to the purposes mentioned under (2), special consideration has been given to a requirement which is very essential to accuracy in such measurements; the requirement, namely, that fluid and prism can be kept for any length of time at a constant temperature. In the heating apparatus provided with this instrument it has been very satisfactorily met.

The accessories themselves are as follows (Fig. 3, Plate XX):

1. A new illuminating apparatus, providing for both a sodium flame and a Geissler (hydrogen) tube as sources of light, and allowing a rapid change to be made from one to the other; also a micrometer adapted to differential measurements of dispersion and simple methods of computation.[1]

Illumination with sodium light is effected with the aid of the reflecting prism *N*, on one side of which is cemented a condensing lens. The flame is placed behind the apparatus, opposite the reflecting prism *N*, and not, as in earlier forms, on one side.

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[1] Compare **Pulfrich**, "Ueber Dispersionsbestimmung nach der Totalreflexionsmethode mittels mikrometrischer Messung," *Z. f. Instrum.* p. 267, 1893.

Illumination with hydrogen light is effected by a Geissler tube *Q* and a condenser *P;* the condenser forms an image of the cross-section of the tube on the prism of the refractometer. A fine adjustment of the illumination is effected by turning *c*, which moves the condenser *P* in a vertical direction. A small screen (not shown in Fig. 3), hinged to the support of the condenser, can be interposed in the upper part of the cone of rays between the condenser and the prism. It serves to obviate difficulties arising from the overlapping of the images which correspond to the different hydrogen lines, by restricting each image to a narrow zone of of light in the immediate vicinity of the observed terminal line.

The illumination is changed from one source to the other by slightly displacing the prism *N*, for which purpose the arm supporting it can be turned about the standard *M*.

Liquids which cannot be investigated in open glass tubes can be protected from contact with the outer air by means of a cover attached to the vessel *S*.

2. A new heating apparatus of special construction, by which perfect certainty is secured in the investigation of fluids up to 100° C. or more, with the greatest possible simplicity in the manipulations.

The heating is effected by passing through the apparatus in the direction indicated by the arrows (Fig. 3), either a stream of water at constant temperature, or steam. Liquids having a constant boiling point can also be used. Generally a reservoir of warm water, placed slightly above the level of the instrument, is a satisfactory source of supply; in certain cases an apparatus specially constructed to give a stream of warm water at constant temperature is recommended.

The prism is heated equally with the substance; it is surrounded on three sides by a hollow casing, through which the stream of warm water flows before it passes into the apparatus for heating the fluid. Corrections for the change in the refrac-

PLATE XX.

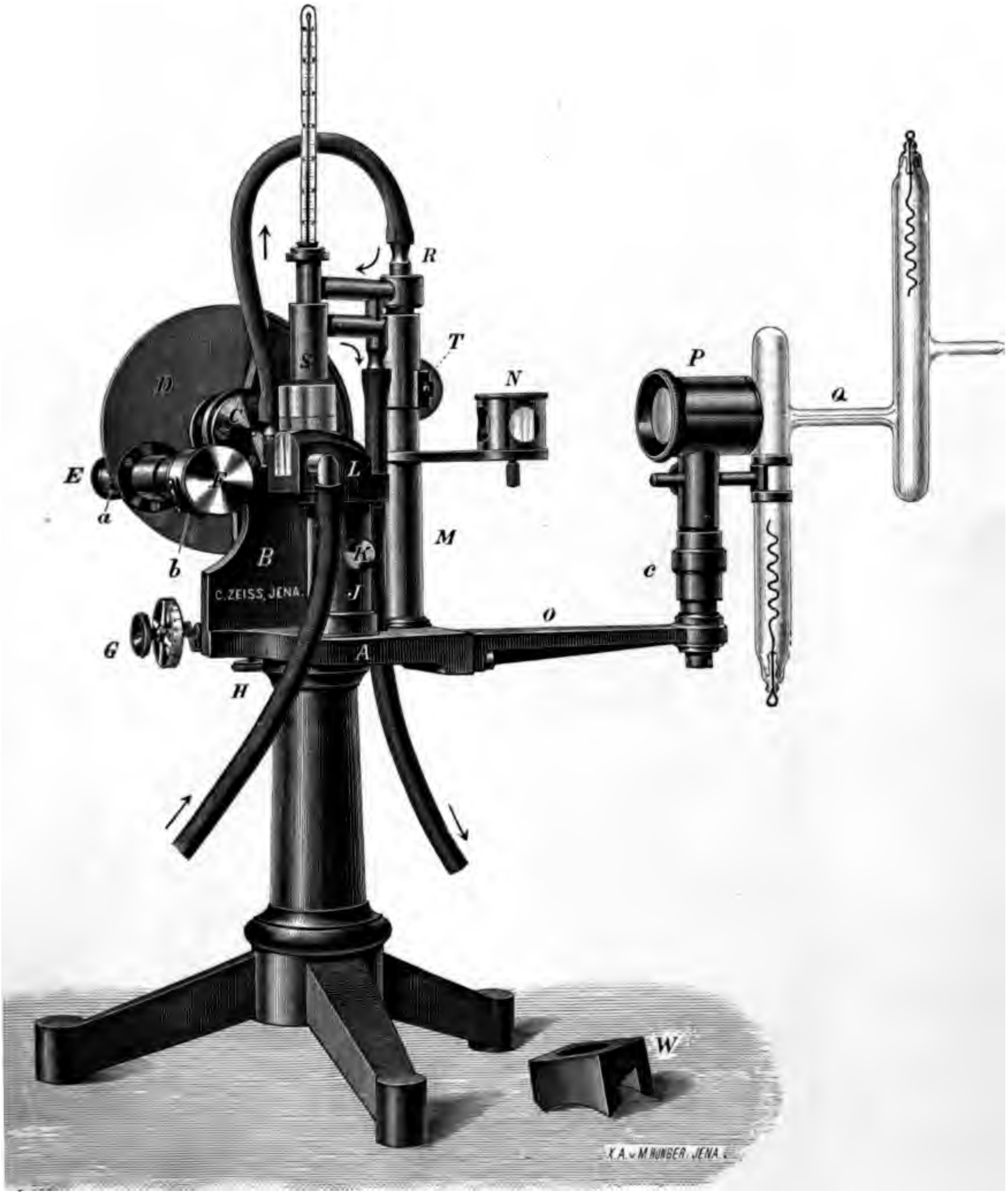

FIG. 3.

tive indices of the prism caused by heating are taken from specially prepared tables, and require no further thought in carrying out the computations.

The fluid is warmed inside the glass cylinder. This is accomplished by means of a silver vessel *S*, which is attached to the standard *M*, and can be moved down or up by the pinion *T*, so as to dip more or less deeply into the fluid.

The interior arrangement of the vessel *S* is shown in Fig. 4. An inner tube, open below, which passes down the middle of *S* nearly to the bottom, causes the stream of water to impinge directly upon the bottom plate of *S*; and since this plate can be brought to within a fraction of a millimeter of the upper surface of the prism, without impairing the accuracy of the observations, it will be seen at once that the temperature indicated by the thermometer may be regarded with absolute safety as the temperature of the fluid.

As a protection to the fluid against loss of heat by radiation, a wooden cover *W* is provided, with a cylindrical hollow, and small windows for the admission of light. This is simply placed over the glass cylinder like a lid. It also serves to protect the fluid from temperature changes when observations are made at the temperature of the room with or without the stream of water, and it acts as a screen to cut off false light. The micrometer attachment consists of the clamp *H*, and the micrometer screw *G* with index and graduated head. The angular separation of the bounding lines is given directly in degrees and minutes within 0'.1, while the circle divisions can be read to 1'.

The heating apparatus can be left on the instrument; when not in use the parts attached to *S* can be moved out of the way by turning them about *M* as an axis.

3. A new form of cell for fluids, made according to a suggestion of Professor Ostwald, by which it is possible to investigate two fluids simultaneously, and to measure directly the differences of their refractive and dispersive powers.

The plan referred to consists in placing a partition of black glass in the cylinder, parallel to the plane of the graduated circle, so as to divide the interior space into two cells, one of which is filled with the fluid which serves as a standard, and the other with that which is to be compared with it,—for example, the solution of any substance in the same fluid. With this arrangement not only are all errors due to differences of temperature avoided, but the measurement of differences in refractive and dispersive powers is reduced to the micrometric measurement of the angular distance between two lines, which are visible in the field of the telescope.

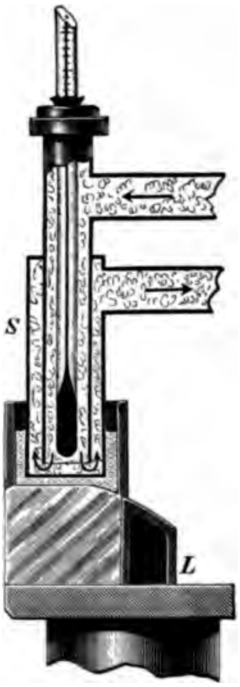

FIG. 4.

No special prism is required for differential measures in the case of solid bodies. The two substances to be compared are cemented together at a flat surface on each, and then treated as a single body; the only precaution to be observed in doing this is to so cut the surfaces I and II that they may be, at least roughly, perpendicular to the plane of separation.

In either case the differential measurements are facilitated by a stop, which can be placed in front of the objective so as to cover its right and left halves alternately.

With respect to the application of the apparatus to the measurements which were also possible with the older construction (determination of n_D) the arrangement of its parts is essentially the same as before. The only features which can be regarded as new in this respect are (aside from the different position of the sodium flame):

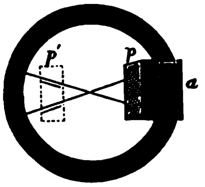

Fig. 5.

A. An attachment, permanently connected with the eyepiece of the telescope, by which the initial direction of the telescope (zero reading of the circle) can be easily and quickly ascertained. It consists of a small reflecting prism (*P*, Fig. 5), so placed between the eyepiece and the cross-wires (which are inclined to each other at an angle of 45°) that it covers part of the latter. The greater part of the field of view, and particularly the intersection of the cross-wires, is however, left free for the direct observation of the limiting rays. A light on the right of the observer, opposite the window *a* (Figs. 3 and 5), furnishes the illumination. The reflected images of the wires, being projected on the bright reflection of the opening of the prism *P*, are very readily found.

B. A stop with elliptical aperture, placed over the middle of the objective. Its purpose is to intercept stray light coming from the upper face of the prism.

By turning the cap on the objective end *F* of the telescope, this aperture, or either of those mentioned above (under 3), can be brought in front of the objective; or the objective can be completely closed as a guard against dust or other injury.

THE MODERN SPECTROSCOPE. XVII.

DESCRIPTION OF A SPECTROSCOPE (THE BRUCE SPECTROSCOPE) RECENTLY CONSTRUCTED FOR USE IN CONNECTION WITH THE 25-INCH REFRACTOR OF THE CAMBRIDGE OBSERVATORY.[1]

By H. F. NEWALL.

THE spectroscope which is described in the present note has lately been constructed for use in connection with the 25-inch visual refractor (the Newall telescope) of the Cambridge Observatory.

It has been arranged solely for photographing spectra, and no provision has been made for visual micrometric measurements.

In designing the spectroscope, and especially in deciding on what may be described in general terms as a single-prism spectroscope, I have been guided by the following considerations. The brighter stars in the northern hemisphere have been studied in considerable detail, and provision has been made for their being further studied at many observatories. A new instrument to be used in connection with an equatorial of large light-collecting power should be designed chiefly with a view to rendering work of high precision possible in the case of the fainter stars. For work of high precision it seems best at present to adopt a spectroscope with collimator and slit, and to provide arrangements for getting comparison spectra from terrestrial sources.

In the case of faint stars, the primary difficulty is to get a photograph at all, however little the purity or definition of the spectrum. It is therefore of the greatest importance to adopt arrangements which involve as little loss of light as possible in the spectroscope itself, and which ensure that as much as possible of the light collected by the object-glass of the equatorial shall pass into the slit of the spectroscope.

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[1] Reprinted from the *Monthly Notices of the Royal Astronomical Society*, January 1896.

Preliminary work with spectroscopes of various constructions has shown that it would be necessary to modify the color correction of the visual refractor by some auxiliary lens, or else to put up with a very limited range of spectrum. The difficulties which arise in consequence of imperfect achromatism, in spectroscopic investigations made in connection with large refractors, have been described by many observers; most recently by Keeler with reference to the Lick telescope (ASTROPHYSICAL JOURNAL **1**, p. 102, 1895), and by Bélopolsky with reference to the Pulkowa refractor (ASTROPHYSICAL JOURNAL **1**, p. 366, 1895).

The spectroscope may be briefly described as having a single large white-flint prism, transmitting a beam of light of circular section and two inches in diameter, and having a camera of fixed length, in which may be used either (1) an ordinary object-glass for giving a short spectrum of a very faint star, the spectrum being in this case $19^{\rm mm}.9$ long from $H\beta$ to midway between H and K, or (2) a telephoto-combination arranged so as to effectively double the length of the camera for giving a greater linear dispersion for medium stars, the spectrum being in this case $44^{\rm mm}.5$ long for the same range as above stated.

It is perhaps of interest to record here the linear extent of the spectrum from $H\beta$ to midway between H and K (the same range as above) for some of the spectrographs lately used by Dr. Vogel at Potsdam (ASTROPHYSICAL JOURNAL **1**, p. 200, 1895).

No. I, used for velocity in line of sight,	$69^{\rm mm}$.
No. II, used for spectra of Mars or Jupiter,	$16^{\rm mm}$.
No. III, used for Nova Aurigae,	$7^{\rm mm}.0$
No. IV, used for β Lyrae,	$8^{\rm mm}.6$

The mode of attachment to the refractor is, I believe, unusual, and may be briefly described as follows:

A correcting lens is inserted in the cone of rays coming from the object-glass of the refractor. It is set about five feet from the uncorrected focus; and the corrected focus is nearer to the object-glass by about eighteen inches. (The effective focal length of the combination is about twenty and one-half feet.) The corrected focus is thus drawn up inside the refractor.

The spectroscope is pushed up partly into the tube of the refractor so that the slit coincides with the corrected focus.

In this arrangement many advantages are gained, notably the following:

(1) An improved color correction results.

(2) Strength is gained in the attachment of the spectroscope to the eye-end.

(3) Space is economized, for the spectroscope is eighteen inches nearer to the object-glass of the refractor.

(4) The whole spectroscope, being attached to a strong framework which is clamped to the focusing tube of the refractor, can be moved bodily in and out (for the purpose of focusing the star on the slit) without altering the adjustment of the parts of the spectroscope.

(5) The convergency of the cone of rays from the object-glass of the refractor can be arranged to have a very convenient value; the convergency for the uncorrected object-glass is about 1 in 14.0, and with the correcting lens it becomes 1 in 10.

(6) As a consequence of the altered convergency, the requisite resolving power can be attained in the single prism with shorter collimator.

The one drawback that I realize at present is that, since the relation between the purity P, the resolving power R, and slit width s, and the ratio ψ of aperture to focal length, is

$$P=\frac{\lambda}{s\psi+\lambda}R,$$

it is clear that the slit-width must, for a given purity and resolving power, vary inversely as ψ. This I regard as a great disadvantage; but it has seemed to me that there was a balance of advantage in favor of the lens.

I was at first inclined to think that the inaccessibility of the slit was an insuperable objection. But the adoption of Huggins' admirable plan of a reflecting slit-plate has got over all the anticipated difficulties.

Having thus briefly indicated the general method adopted, I proceed to describe some of the details.

THE EYE-END OR BREECH-PIECE OF THE 25-INCH REFRACTOR.

No doubt many of the conveniences of the adopted method of attaching the spectroscope depend on the arrangement of the eye-end of this special refractor. The sturdy massiveness of Cooke's work has formed a splendid foundation, to which the spectroscope has been fitted.

The steel tube of the refractor is cigar-shaped, wider in the middle than at the ends. At the eye-end the steel tube has a diameter of 21 inches, and to it is fitted a strong iron casting which contracts the opening with a rapid taper down to 8½ inches, and forms a strengthening piece with a turned flange. Into the opening thus left is fitted a massive breech-piece (an arrangement of draw tubes, position circle and focusing mechanism), ending in a flange with a kind of bayonet joint, to which the various adapters for eyepieces, micrometer, solar eyepieces, etc., can be fitted. All apparatus fitted to the bayonet joint can be rotated in connection with the position circle, and can be racked in and out by means of the focusing screw through a range of 4 inches. The breech-piece weighs about 1½ cwt., and its weight gives an idea of its strength. It is to this bayonet-joint flange, the aperture of which is 5¾ inches in diameter, that the spectroscopic appliances are attached. The plane of the flange, when racked in as far as the focusing screw will take it, is about 7¾ inches nearer to the object-glass than the uncorrected focal plane.

THE CORRECTING LENS.

A simple convexo-concave lens of aperture 5 inches, and of focal length 154 inches for light of wave-length 5890–6 is set in the convergent beam of rays coming from the object-glass of the refractor at a distance of about 62 inches from the focus, or, as I shall now call it, the uncorrected focus. The corrected focus is about 18 inches nearer to the object-glass.

The lens is mounted at the end of a brass tube, and the other end of the tube is provided with a heavy flange. The tube is pushed, lens first, into the refractor, and the flange is clamped into the bayonet joint at the end of the breech-piece.

The position of the lens can be altered by the focusing screw, but when the lens is pushed in as far as it will go, then the new, or corrected, focus is inside the tube which holds the correcting lens about 11 inches from the new flange on the breech-piece.

It is unnecessary to go into details concerning such a lens, inasmuch as Keeler has recently published (ASTROPHYSICAL JOURNAL **1**, p. 101, 1895) a note on work which is in great measure identical with that which I undertook in considering the possibility of getting a satisfactory improvement of the color curve with a simple lens. Keeler has rejected the solution "for the general case of large telescopes," on the ground that the alteration which the use of such a lens would produce in the aperture of the convergent beam (*i. e.*, the ratio of the diameter of the cross-section of the convergent beam to the distance of the cross-section considered from the focal plane) is excessive. In the case he considers the ratio is altered from 1:19 to 1:5, and this would involve the use of a collimator of such unusual proportions as to be impracticable.

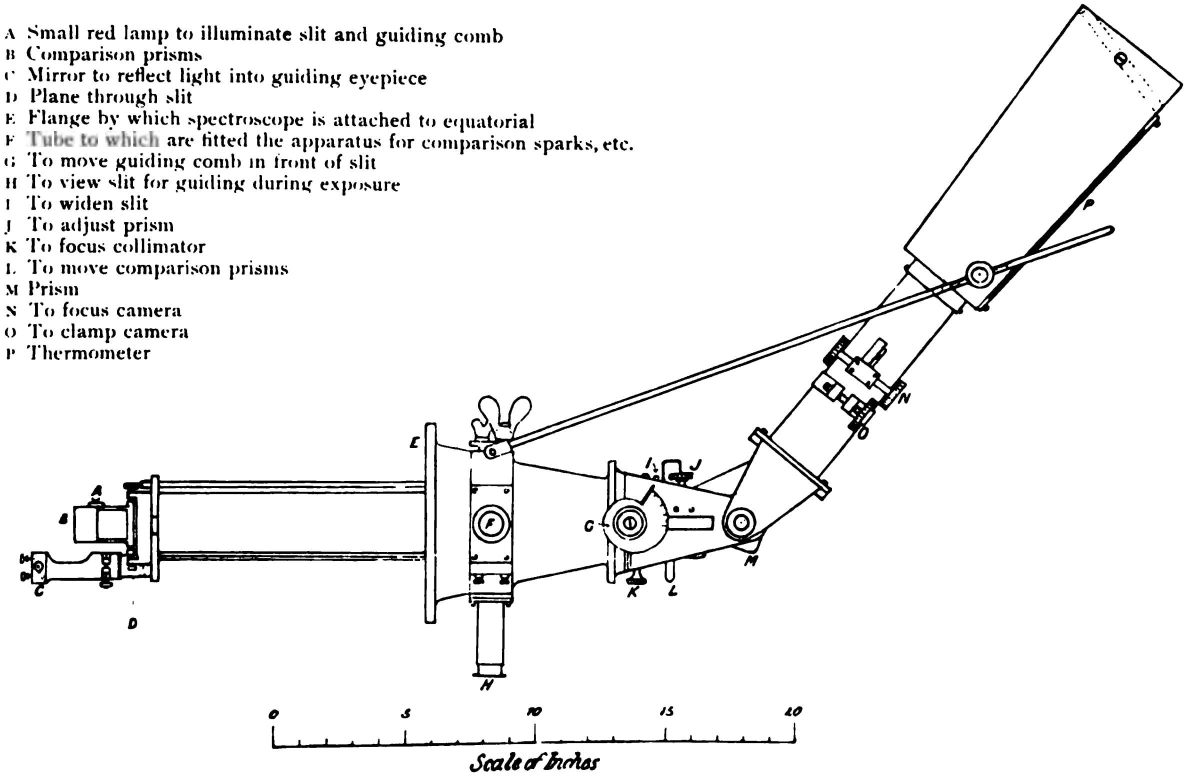
But the question is—is it possible to produce a considerable change in the color correction without excessive change in the ratio referred to? Elementary calculations, similar to those published by Keeler, showed that it was worth while to have a lens made, and experimental determinations of the corrected separation of the foci for different colors for the actual correcting lens used have convinced me that the improvement is considerable. It is clear that if the separation of the foci were reduced only in the same proportion as the convergency ratio, no advantage would be gained: when one of two colors was in focus on the slit the circle of aberration for the other color would be just as great as without the correcting lens.

My lens is arranged to give a convergent beam, with ratio 1:10, whilst the uncorrected object-glass has a ratio 1:14.0.

PLATE XXI.

DESCRIPTION OF PLATE

A	Small red lamp to illuminate slit and guiding comb
B	Comparison prisms
C	Mirror to reflect light into guiding eyepiece
D	Plane through slit
E	Flange by which spectroscope is attached to equatorial
F	Tube to which are fitted the apparatus for comparison sparks, etc.
G	To move guiding comb in front of slit
H	To view slit for guiding during exposure
I	To widen slit
J	To adjust prism
K	To focus collimator
L	To move comparison prisms
M	Prism
N	To focus camera
O	To clamp camera
P	Thermometer



THE BRUCE SPECTROSCOPE OF THE CAMBRIDGE OBSERVATORY

Under these circumstances the collimator of the spectroscope is of very convenient dimensions—namely, 2 inches aperture and 20 inches focal length. A comparison of the diameter of the circles of aberration on the slit, first for the uncorrected object-glass and second for the corrected object-glass, shows clearly the advantage gained. If the light focused on the slit in each case is light of wave-length 4860 ($H\beta$), the circles of aberration deduced from actual measurement for $H\gamma$ and $H\delta$ have diameters as follows:

	Uncorrected O.G. mm	With Correcting Lens mm
$H\beta$	0.00	0.00
$H\gamma$	0.81	0.36
H	1.94	0.97

Photographs of star spectra are satisfactorily uniform from λ 5896 (D) to λ 4470. I refer here to uniformity of density; in another place I give suggestions as to a cause of unsatisfactory definition at the ends.

The following point with respect to the focusing of the star on the slit may be noted. The distance between the slit and the correcting lens is fixed when the collimator is clamped in the framework. The focusing is accomplished by moving both spectroscope and correcting lens simultaneously in or out by means of the focusing screw. The distances between the correcting lens and the conjugate foci are so related that the movement of the lens and spectroscope through any given small distance produces a movement of the star-image through nearly exactly one-half that distance with respect to the slit. The focusing, which is of great importance, can thus be done with great accuracy.

THE FRAMEWORK OF THE SPECTROSCOPE.

The frame of the spectroscope consists of a heavy, hollow, conical casting of gun-metal with a flange at each end. The larger flange is that by which the whole spectroscope is clamped to the equatorial by means of four large thumbscrews; to the smaller flange is attached a strong ribbed aluminium casting, carrying the pivots about which the whole camera can turn, and between which the prism is mounted.

The collimator is held in the conical casting, the lens projecting through a hole in the smaller flange and the aluminium casting, and the plane of the slit being about 11 inches from the plane of the larger flange. The whole collimator is arranged to slide through a small range (about ½ inch) so that the distance between the slit and the flange may be adjusted. The final focusing of the star-image on the slit is accomplished by moving the whole spectroscope in or out by means of the large focusing screw on the breech-piece.

About midway between the flanges on the conical casting the casting is thickened, so that a cylindrical ring is formed which facilitates the attachment of several accessory arrangements: (i) a telescope and reflectors to enable the observer to view the slit as from in front; (ii) condensing lenses and reflectors to throw an image of a spark or tube for comparison spectra upon the slit; (iii) a clamping screw to hold the stay-rods by which the camera is prevented from turning about the pivots; and several other small things which it is not necessary to specify.

THE COLLIMATOR AND SLIT AND GUIDING COMB.

The collimator has a focal length of 20½ inches (520^{mm}) and an aperture of 2⅛ inches (54^{mm}), the object-glass being a visual achromatic.

The stout collimator tube is made so that it can slide through a small range in the frame of the spectroscope; and when the tube is clamped in position the object-glass can be moved relatively to the slit by means of a rack and pinion. A scale is attached by which the focus-reading can be read off.

The slit is arranged after the admirable device of Dr. Huggins. The jaws are made of speculum-metal, and the exposed faces are highly polished, so as to form a single plane surface, which is inclined at a small angle to the axis of collimation. Great care was taken to work the sharp edges in a proper manner.

When the image of a star is thrown upon the slit, some porion of the light passes through the slit; the rest is reflected by he polished faces of the jaws onto a small mirror, fixed in front f the slit and displaced slightly to one side, so as not to interere with the incident pencil. The mirror, together with a system f lenses and a reflecting prism, enables the observer to view he slit: he looks into an eyepiece attached to the conical framevork in a direction perpendicular to the axis of the collimator, nd sees the slit and any images (whether of star or of spark or comparison spectra) that may fall upon it from the proper uarter.

In front of the slit is set a small movable guiding comb, vhich enables the observer to set the star-image on any required art of the slit. The teeth of the comb cover certain parts of he slit, and leave the rest exposed. By a suitable mechanism he comb can be either moved by a very small amount up and lown the slit, or altogether withdrawn so as to expose the whole lit. By making the teeth of the comb twice as wide as the gap etween them, it is arranged that three spectra can be set side y side—*e.g.*, a star spectrum taken between two spark spectra, ne of which is taken before, the other after, the star spectrum. n this mode of procedure any changes of adjustment that may ave arisen during the exposure for the star spectrum, in conseuence of change of temperature or in the position of the spectrocope, may be at once detected in the photograph.

The beautiful device of Dr. Huggins' reflecting slit is only pen to one objection, so far as I am aware. Let us suppose it s desired to investigate a spectrum near $H\gamma$. In this case it is ecessary to focus $H\gamma$ light on the slit and to keep it on the slit. t is difficult to do this, in consequence of the chromatic aberraion of the equatorial; but the following device has proved fficacious. From time to time the star is observed on the slit vith a small direct-vision compound prism held between the eye nd the guiding eyepiece in such a way that the length of the pectrum is parallel to the length of the slit. The slit then ppears as a fine dark line running along the length of the pectrum, which is narrow at the part or parts focused on the slit, and has at any other part a width determined by the diameter of the circle of aberration of the light corresponding to that part. The star is then moved until the narrow parts of the spectrum fall on the slit. The prism is then removed, and the position of the slit with respect to the slightly blurred star-image is noted, so that guiding can be continued with only occasional recourse to the prism.

In such work as the investigation of the spectrum of special parts of a planet or a nebula the reflecting slit is invaluable.

THE PRISM.

The prism at present used is a white dense flint prism of 60°. The height is 2⅛ inches (54^{mm}), and the length of the side of the triangular section is 3⅜ inches (86^{mm}).

The resolving power for λ 5896 is about 7600; $\delta\lambda = .8$ tenth-meter.
" " λ 5000 " 12000 " .4 "
" " λ 4250 " 22000 " .2 "

The edges and angles of the prism are all ground blunt, and the prism is partly encased in aluminium sheet, which is bent so as to cover the triangular faces (the "top" and the "bottom") of the prism and also the ground rectangular base, but so as to leave the two polished rectangular faces free. Two small gun-metal bosses are fitted to the aluminium case, one fixed on the bottom, the other being adjustable within small limits on the top of the prism. Fine center-holes are drilled through the bosses and the line joining them is made parallel to the refracting edge, the final adjustment being made by moving the adjustable boss by four screws. Two screws with fine conical points pass through the pivots about which the camera turns, and the prism is held in its case between these conical points or male centers, which are screwed through the pivots into the female centers in the bosses. The prism thus held is free to turn about an axis through the male centers. An arm projecting from the top of the prism-case is pressed by a spring against the end of a screw which is fixed to the frame-work, and a slow motion for adjusting the prism for minimum deviation is thus provided.

This mode of holding the prism has proved very satisfactory. The slit at the end of the collimator is adjusted to parallelism with the line joining the male centers, and this ensures parallelism with the refracting edge of the prism, provided that the line through the female centers has been adjusted.

THE CAMERA.

The camera is made of a brass tube about 10 inches long joined rigidly to a tapered box of rectangular section, made of aluminium sheet and having a length of 10 inches. The total length of the camera is thus 20 inches.

The following object-glasses can be used in it, each having an aperture of 2⅛ inches (54^{mm}).

(1) A visual achromatic object-glass of focal length 20 inches (508^{mm}).

(2) A plano-convex quartz lens of focal length 20 inches. The use of an uncorrected lens of this kind is convenient when flat photographic plates are used. With two similar achromatic lenses in the collimator and camera, the result of the over-correction of both lenses is to give a spectrum which cannot be in focus over a considerable range unless a curved plate or film is used. If an uncorrected lens is used in the camera in connection with an over-corrected lens in the collimator, the spectrum is flatter. Whether it is better to use glass or quartz for the simple lens depends upon the character of the color correction of the achromatic object-glass used in the collimator.

In laboratory work I have used a spectacle lens of 36 inches focal length in connection with an over-corrected "achromatic" collimating lens and have got admirable spectra from the D lines to λ 3800 photographed in sharp focus on a single flat plate without tilting the plate. I have not seen the method described, but it is so simple that it is most probably known.

(3) A telephoto-combination, designed and used in such a way as to have an equivalent focal length of about 40

inches (1016^{mm}) though the extreme *actual* length of the camera is the same as with the other object-glasses, namely 20 inches (508^{mm}).

The use of this optical device was only decided upon after numerous experiments, and I take this opportunity of expressing my obligations to Messrs. Dallmeyer for their kindness in letting me try some of their combinations before having a pair made for use in this spectroscope.

If justification of the use of this method be required, it may be based on the following considerations. The prism used is of such dimensions that the resolving power is considerably higher than that which a photographic film with its markedly granular structure can ever do justice to. The theoretical resolving power of my prism is a little more than one of Professor Vogel's compound prisms. Professor Vogel[1] has expressed the opinion that the performance of his prisms would have warranted a large increase in the focal length of the camera, but such an increase would have increased the linear dispersion so much that only the brightest stars could have been observed with the Potsdam refractor. The question therefore presents itself: Is it better to use two prisms and a short camera or one prism and a long camera? The only considerations which bear on the point are practical, and it appears to me that the coarseness of granularity of available photographic plates is the most important factor; for it would seem useless to employ an optical resolving power greater (except by an arbitrary amount for margin) than the defining power of the photographic plate. If the necessary resolving power can be attained with a single prism of manageable dimensions, the balance is in favor of the single prism, for it involves a smaller loss of light.

SCALES ON THE INSTRUMENT.

The importance and convenience of having scales on the instrument, by which every adjustment of every adjustable part can be recorded, cannot be overestimated.

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[1] *Publ. d. Astroph. Obs. zu Potsdam*, 7, pp. 20, 21, 1892.

The following scale readings are taken for each exposure made on the telescope:

1. Position angle of the slit, usually 90°.

2. Focus reading, localizing the position of the slit amongst the colored images of the star formed on the collimation axis of the equatorial.

3 and 4. Focus readings of the collimator and camera.

5. Inclination of the photographic plate.

6. The inclination of the axes of camera and collimator.

7. Width of the slit.

8. Temperature recorded by a thermometer attached to the camera.

9. The part of the slit exposed at different times during any exposure.

There is still needed a tenth scale to record the position of the prism.

SOME NUMERICAL DETAILS.

The weight of the spectroscope is twenty-six pounds; the weight of the flanged tube which holds the correcting lens, thirteen pounds.

Assuming, for the sake of definiteness, that determinations of radial velocity would be made by measurements near $H\gamma$, the following details give a more precise idea of the conditions under which such measurements could be made with the spectroscope described in this note.

The spectrum near $H\gamma$ has a linear dispersion 1^{mm} to 21λ (tenth-meters). Taking the minimum measurable quantity to be $0^{\mathrm{mm}}.001$, this would correspond to $0^{\lambda}.021$, or to $1^{\mathrm{km}}.5$/sec., or 0.9 mile/sec. (In Vogel's classical researches, $0^{\mathrm{mm}}.001$ corresponded to $0^{\lambda}.013$, or $0^{\mathrm{km}}.9$/sec., or 0.6 mile/sec.)

The diameter of the first diffraction-ring in the corrected image formed by the object-glass of the equatorial and the correcting lens is, for $H\gamma$, $0^{\mathrm{mm}}.011$.

Near $H\gamma$, since the resolving power of the prism is 22,000, the purity of the spectrum can never be advantageously greater than

7000. The following table shows the relation between the purity and the slit-width.

Purity	Slit-width mm	Spectrum pure enough to separate two lines for which $\delta\lambda$ is
7300	0.0086	0.60 tenth-meter
5500	0.025	0.79 "
4340	0.035	1.00 "

Actual measurement shows that the distance between the centers of neighboring grains on a photographic film of average goodness lies between $0^{mm}.01$ and $0^{mm}.035$, and a fair average value seems to be $0^{mm}.02$ or $0^{mm}.025$. With the telephoto camera the image of the slit is twice as wide as the actual slit. It is thus seen that, with a slit-width $0^{mm}.025$, the image on the plate involves two grains in its width.

It will be noted that the width of slit is, in the case just dealt with, twice as wide as the diameter of the first diffraction-ring in the star image. It would seem to me to be convenient to introduce the term "tremor-disk." The name more or less explains itself: it is easiest to state what it is intended to convey by reference to a photograph of a star taken with a long exposure. The star-image moves about on the plate in consequence of atmospheric tremor, and produces its effect at each spot on which it rests; the developed image is strongest where the star has most frequently rested; the distribution of density is probably symmetrical about the mean position of the star, and the intensity at different points along a diameter of the resulting tremor-disk is probably fairly well represented by a "law of errors" curve. Apart from the photograph, which shows the summation of the effects, the tremor-disk may be conceived as existing in time, so to speak; and the effect produced in a slit-spectroscope depends on the relation between a certain area of tremor-disk and the area of the slit illumined by it. The tremor-disk is of greater importance, so far as the design of a stellar spectroscope is concerned, than the diffraction-disk, which has generally been considered.

The tremor-disk at Cambridge frequently has a diameter of $8''$ or even $10''$; and on average nights it is probably fully $5''$.

Assuming that the bright central part is 3″, this would be a disk whose linear diameter is $0^{mm}.09$, and whose area is three times as great as the illumined part of the widest slit which it is thought advisable to use.

The instrument has been named the Bruce Spectroscope, since it is one of the numerous outcomes of Miss Bruce's Grant in Aid of Astronomical Research. A portion of this grant was, through Professor E. C. Pickering, awarded to Professor Adams for the purchase of an instrument for the Cambridge Observatory; and it was decided to use it in providing a spectroscope for the 25-inch refractor. As the spectroscope is, in this sense, of American origin, it is a special satisfaction to record that the optical parts were (with the exception of the Dallmeyer telephoto-combination above referred to) made in America. They were supplied by Mr. Brashear, of Allegheny, and the excellence of their finish and performance is admirable. The mechanical parts of the instrument were made by the Cambridge Scientific Instrument Company; and I gladly take this opportunity of saying how much their care in carrying out the somewhat troublesome design, and the ingenuity with which many difficulties were overcome, have contributed to the success of the instrument.

At the present moment I am not quite prepared to express a final opinion on the success of the general design of the instrument, for there are some points on which I wish to have more precise knowledge. I had hoped to have gained that knowledge before presenting this description, but the weather has been so unfavorable—there has not been a single observing night in the past four weeks—that my hopes have been frustrated, and it has seemed better to present the description at once and leave for a later communication some account of the points I have referred to.

Meanwhile it will probably be of interest to give the following particulars with reference to the spectra photographed with the telephoto camera and with a slit-width of $0^{mm}.02$.

With an exposure of seven minutes, the spectrum of Venus comes up with excellent clearness.

With an exposure of ten minutes, the spectrum of α Lyrae from D to $H\gamma$ is over-exposed in some parts.

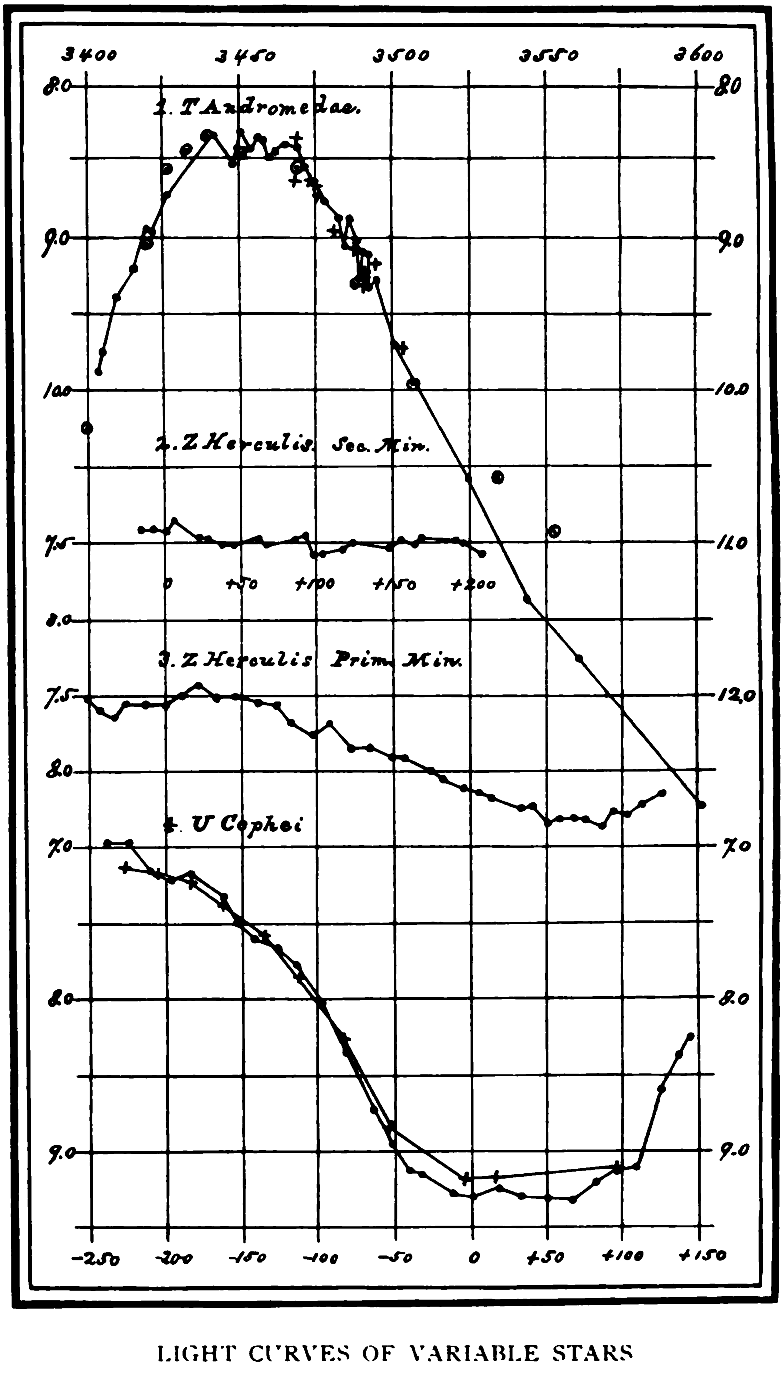
An exposure of twenty minutes gives the spectrum of α Aurigae at $H\gamma$ at its best.

An exposure of thirty minutes is enough for γ Cassiopeiæ, and with this exposure the doubleness of the bright hydrogen lines, $H\beta$ and $H\gamma$, is clearly seen.

An exposure of forty or fifty minutes is required to give a spectrum showing the green bands in α Orionis satisfactorily With this exposure the spectrum is shown from D to λ 4400.

It should, however, be stated that the width of the spectrum is, in the case of stars, small—rather less than 1^{mm}. This small width is found enough for measurement with the microscope, and I have not as yet made any wider spectra for inspection without the microscope.

PLATE XXII.



LIGHT CURVES OF VARIABLE STARS

LIGHT CURVES OF VARIABLE STARS DETERMINED PHOTOMETRICALLY.

By EDWARD C. PICKERING.

A NEW form of photometer for measuring the brightness of faint stars was described in THE ASTROPHYSICAL JOURNAL, **2**, 89. It has been used in determining the light curves of a number of variable stars, and some of the results are represented in Plate XXII. In any careful study of the causes of the variation of different stars, photometric measurements are almost indispensable. Argelander's method, in which the differences in brightness of the variable and of other stars of nearly equal brightness are estimated in grades, serves very well in determining the period of the variation. But as soon as we wish to study the nature and amount of the changes the magnitudes must be reduced to a photometric scale. If an arbitrary scale is used, like that of Argelander, we have no certainty regarding the amount of the change. The unit is different for different parts of the scale, and the scale itself varies in different parts of the sky. Moreover, for stars fainter than the ninth magnitude the standard is very uncertain. It is doubtful which is brighter, the twentieth magnitude of Herschel or the twelfth of Struve. Again, repeated observations cannot be made by the method of Argelander, as when the observer has once made up his mind regarding the relative brightness of two stars, he cannot obtain an independent estimate. Every observer of the Algol stars knows how much an estimate may be affected by a previous knowledge of the predicted time of minimum. The method of grades possesses many advantages, and is used at Harvard College Observatory in determining the brightness of variable stars of long period. Many stars are observed, once each night, so that the next night the observer has forgotten his previous estimates and is able to make unbiassed observations. The magnitudes of the comparison stars are determined photometrically, and the entire system of observations is thus reduced to a scale which is sensibly uniform throughout, and is the same in all parts of the sky. There are some great advantages in measuring photometrically the brightness of variables directly instead of indirectly by comparison with other stars. Measures may be repeated indefinitely since each is independent of those preceding it, and the variation is found at once without the laborious operation of measuring a number of other stars.

With the photometer mentioned above any two stars within half a degree of each other may be compared, and the variable may thus be observed continuously during an entire evening. Four examples of light curves derived from observations obtained with this instrument are shown in Plate XXII. The observed points are represented by circular dots. Corresponding magnitudes derived from photographs are represented by small circles, and the results of measures with the meridian photometer by small crosses. In each case the vertical scale is such that one division represents half a magnitude. The zero points of the scales have not yet been determined with accuracy, as the measures here described only give differences in magnitude. The absolute magnitudes will be determined later in each case with the meridian photometer. The horizontal scale for Fig. 1 is such that one division represents twenty-five days, in the other figures it represents fifty minutes. The results of measures of the variable star of long period, T Andromedae, are shown in Fig. 1. Six sets of four settings each were made on thirty-five nights beginning July 29, 1895, and ending February 12, 1896. A maximum is indicated on September 15, 1895. The small circles representing the photographic results are in general derived from the mean of two estimates by the method of grades, of the images on five photographic plates on different nights. All of the photographic magnitudes have been diminished by 0.80 to allow for the red color of the star. The later photographs show a systematic deviation, probably due either to a change in the color of the star as it becomes fainter or to a difference in the scale. Omitting the last two points, the average deviation of the others, is ± 0.09. Each observation with the meridian photometer is derived from eight photometric settings. The average deviation is ± 0.08.

The advantages of the photometric method in the case of a star suspected of changing rapidly is illustrated in Fig. 2. It shows the results of the measures of the Algol variable Z Herculis on the evening of September 14, 1895, from $13^h\ 51^m$ to $17^h\ 35^m$ G. M. T. The total number of settings is 368, divided into 23 groups of 16 settings each. According to the ephemeris of Professor Dunér (ASTROPHYSICAL JOURNAL, **1**, 289), a secondary minimum of this star should have occurred on that evening at $14^h\ 6^m$ G. M. T. No evidence of such a minimum appears from these observations, the separate results differing from the mean by only ± 0.04. The observations of one of the principal minima of the same star, on July 26, 1895, are shown in Fig. 3. Continuous observations lasting for more than six hours were made and consisted of 560 settings divided into 35 groups. The form of the light curve is well shown, and also its deviation from the ephemeris, which amounts to seventy minutes. Both of these quantities would be better represented if the vertical scale was increased, but the nature of the variation of the different stars seemed to be better shown by using the same vertical scale for all. Similar observations have been made of ten other minima of this variable, the observations each night generally lasting for more than three hours.

Observations of the Algol variable, U Cephei, on December 3, 1895, are shown in Fig. 4. They lasted for about seven hours, during which time 448 settings, divided into 28 groups were made. The haziness increased during the evening and at about the predicted time of minimum the star was partially obscured by well-marked bands of cirrus cloud which were clearly seen in the moonlight. The curve shows that the results are not sensibly affected. The difference in brightness of the variable, +81° 25, and the comparison star, +81° 27, is the quantity measured. As their distance apart is only about 14′, their brightness is equally affected by clouds. An error of about half an hour in the ephemeris is indicated by these observations.

A series of measures of the same star was made at the same time with the meridian photometer. The results are represented by crosses. They are instructive as showing the accuracy attainable with this instrument when the accidental errors are reduced by repeating the measurements. Four settings were made of the photometer circle to determine the difference in brightness of λ Ursæ Minoris and the star to be measured. Two such sets of observations of the variable were made, one of + 81° 27, and then two of the variable, thus forming a group of twenty settings. This was repeated fifty-five times during the six hours of observation. The total number of settings was 1100, 880 on the variable and 220 on + 81° 27. Each point on the curve represents the mean of five groups. The time of observing a group was four minutes, and the time spent on each setting was ten seconds. This is about the rate at which settings are made in the regular work with this instrument. The errors seem to be extremely small, although the conditions were not especially favorable. The clouds mentioned above stopped observations for an hour and a half after the minimum. Although their effect was insensible with the other photometer in which stars but a few minutes apart were compared, they could not be neglected with the meridian photometer, since in it the stars are compared with λ Ursae Minoris, which is several degrees distant. The Moon also, which was full on the preceding day, combined with the haze to render the variable at minimum so faint that it could be seen and measured only with great difficulty.

A systematic difference, somewhat exceeding a tenth of a magnitude, appears to exist between the two instruments. It is probably due to the variation of the planes of polarization of the different portions of a ray of light, a part of which passes obliquely through prisms of Iceland spar, or to similar sources of error. This will be a subject for future investigation.

The four principal series of measurements were made by Mr. O. C. Wendell with the 15-inch equatorial of this Observatory. The photographic magnitudes of T Andromedae were determined by Mrs. Fleming, and the observations of U Cephei with the meridian photometer were made by the writer.

HARVARD COLLEGE OBSERVATORY,
March 3, 1896.

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EMENTS. IV.

D PALLADIUM.

ROBERT R. TATNALL.

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ultra-violet lines of Rhodiu
thus completing the present seri
ch previous portions have appeared
NAL for January, February and Octobe

llowing abbreviations are used in the table
s indicates *sharp;* n indicates *hazy.*

RHODIUM.

(*W.-l. 3000 to 4500.*)

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
[illegible]	4	3263.268	5	3360.038	3	3435.039	20 r
3004.555	2	3271.736	5	3360.947	4	3440.671	12
3024.010	3	3280.664	5	3362.330	2	3442.775	2
3070.006	0	3281.822	3	3368.918	1	3447.883	4
3094.081	5	3282.455	5	3372.391	6	3448.723	3
3100.407	2	3283.695	8	3372.668	1	3450.435	4
3100.550	2	3289.266	4	3377.282	3	3451.298	3
3115.020	2	3289.750	2	3377.856	2	3455.365	6
3121.873	3	3294.404	3	3381.589	1[1]	3455.571	3
3123.814	4	3296.842	2	3385.924	3	3457.216	4
3137.824	2	3300.593	4	3389.361	2	3458.072	5
3152.719	1	3302.712	5	3391.927	1[1]	3462.184	20 r
3155.893	3	3303.068	4	3395.040	1	3469.770	8
3170.843	2	3323.228	15	3396.960	20 r	3470.805	16 r
3185.710	2	3331.230	2	3399.839	5	3472.393	7
3189.164	4	3331.381	2	3406.094	3	3474.920	15 r
3191.305	6	3338.687	4	3407.883	2	3478.640	2
3194.660	1	3343.039	2	3412.417	5	3479.053	15 r
3197.248	4	3344.340	2	3420.312	2	3484.184	4
3214.440	2	3345.156	10	3422.434	2	3487.363	2
3237.777	2	3345.707	4	3424.532	7	3487.609	2
3261.175	2	3346.071	1	3432.238	2	3491.218	2[1]

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[1] Not certainly due to Rhodium.

THE ARC-SPECTRA OF THE ELEMENTS. IV.

RHODIUM, RUTHENIUM AND PALLADIUM.

By **Henry A. Rowland** and **Robert R. Tatnall.**

We give below the results of our measurements of the wave-lengths of violet and ultra-violet lines of Rhodium, Ruthenium and Palladium, thus completing the present series of measurements, of which previous portions have appeared in The Astrophysical Journal for January, February and October, 1895.

As before, the following abbreviations are used in the tables: r indicates *reversed;* s indicates *sharp;* n indicates *hazy.*

RHODIUM.

(*W.-l. 3000 to 4500.*)

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
2986.321	4	3263.268	5	3360.038	3	3435.039	20 r
3004.555	2	3271.736	5	3360.947	4	3440.671	12
3024.019	3	3280.664	5	3362.330	2	3442.775	2
3076.006	6	3281.822	3	3368.918	1	3447.883	4
3084.081	5	3282.455	5	3372.391	6	3448.723	3
3100.407	2	3283.695	8	3372.668	1	3450.435	4
3100.556	2	3289.266	4	3377.282	3	3451.298	3
3115.026	2	3289.750	2	3377.856	2	3455.365	6
3121.873	3	3294.404	3	3381.589	1[1]	3455.571	3
3123.814	4	3296.842	2	3385.924	3	3457.216	4
3137.824	2	3300.593	4	3389.361	2	3458.072	5
3152.719	1	3302.712	5	3391.927	1[1]	3462.184	20 r
3155.893	3	3303.068	4	3395.040	1	3469.770	8
3179.843	2	3323.228	15	3396.960	20 r	3470.805	16 r
3185.710	2	3331.230	2	3399.839	5	3472.393	7
3189.164	4	3331.381	2	3406.694	3	3474.920	15 r
3191.305	6	3338.687	4	3407.883	2	3478.640	2
3194.660	1	3343.039	2	3412.417	5	3479.053	15 r
3197.248	4	3344.340	2	3420.312	2	3484.184	4
3214.440	2	3345.156	10	3422.434	2	3487.363	2
3237.777	2	3345.707	4	3424.532	7	3487.609	2
3261.175	2	3346.071	1	3432.238	2	3491.218	2

[1] Not certainly due to Rhodium.

RUTHENIUM.

(*W.-l. 2975 to 4200.*)

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
2974.095	2	3096.669	4	3238.660	3	3344.679	2
2974.457	1	3097.337	1	3239.727	2	3345.457	2
2976.700	3	3097.708	2	3241.360	3	3347.757	2
2977.037	4	3099.390	4	3243.632	3	3348.153	1
2979.834	2	3100.945	4	3251.459	1	3348.847	2
2980.056	2	3105.523	1	3252.029	1	3352.075	2
2982.048	2	3106.954	1	3253.041	2	3353.790	2
2989.061	5	3107.825	2	3254.670	{ 3	3359.239	5
2989.768	1	3110.650	2	3254.834	{ 3	3362.151	3
2993.385	2	3112.031	2	3256.460	2	3362.473	[illegible]
2995.077	4	3112.792	1	3258.173	2	3364.243	[illegible]
2997.006	2	3118.182	2	3259.805	2	3368.524	[illegible]
2997.536	2	3118.799	2	3260.301	1	3368.604	
2997.730	2	3124.279	3	3260.477	5	3371.992	
2998.458	2	3124.480	1	3261.256	1	3374.790	
3001.751	3	3124.720	1	3263.984	1	3378.170	
3006.699	3	3126.075	3	3264.688	{ 2	3379.744	
3008.366	2	3129.951	2	3264.790	{ 2	3380.308	
3008.906	2	3132.995	3	3268.346	4	3385.297	
3013.030	2	3136.671	3	3273.208	4	3385.608	
3013.468	2	3140.604	1	3274.834	4	3385.836	
3020.985	4	3141.094	2	3277.697	3	3387.369	
3033.564	3	3144.383	2	3285.066	3	3388.846	
3034.169	2	3147.326	1	3294.233	4	3389.644	[illegible]
3038.284	2	3150.816	2	3296.248	3	3392.032	2
3040.420	3	3153.941	3	3296.780	3	3392.672	5
3042.587	3	3160.042	5	3297.389	2[1]	3401.646	2
3042.944	2	3168.678	4	3298.089	3	3401.876	4
3045.828	3	3174.254	2	3298.549	2	3406.025	2
3048.603	2	3177.170	2	3299.466	2	3406.731	3
3048.900	3	3186.162	4	3304.126	2	3409.424	5
3055.039	4	3188.468	4	3304.951	2	3411.780	4
3058.891	1	3189.843	1	3306.310	4	3412.939	3
3059.275	2	3190.096	4	3311.096	2	3414.782	2
3064.951	4	3192.191	3	3315.363	4	3416.320	2
3068.363	2	3196.725	3	3315.579	2	3417.466	10 r
3071.711	1	3201.631	2	3316.524	4	3418.117	2
3073.442	4	3213.105	3	3318.025	3	3419.389	2
3076.883	2	3216.646	3	3318.965	3	3420.236	3
3081.010	3	3220.199	1	3325.136	3	3426.089	2
3083.257	1	3221.311	1	3327.843	2	3428.460	15 r
3084.637	1	3223.394	4	3332.190	2	3428.769	5
3086.182	2	3226.502	4	3332.781	2	3429.689	7
3089.259	3	3227.027	1	3335.836	4	3430.908	4
3089.916	2	3228.007	3	3339.690	6	3432.348	3
3090.348	2	3228.280	1	3341.230	2	3432.896	4
3091.980	2	3228.651	3	3341.365	1	3433.397	3
3094.507	2	3232.872	2	3341.811	3	3435.327	4

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[1] Not certainly due to Ruthenium.

RUTHENIUM.—*Continued.*

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
3436.475	3	3593.178	13 r	3717.822	2 [2]	3825.074	2
3436.883	20 r	3596.342	10 r	3719.468	4	3828.319	5
3438.510	5	3599.914	5	3725.117	3	3828.849	2
3440.351	5	3601.630	3	3726.239	5	3831.934	4
3449.107	1	3605.785	3	3727.073	15 r [3]	3835.191	3
3456.763	3	3608.878	4	3728.173	15 r	3838.201	3
3462.186	4 [1]	3609.247	2	3730.577	10 r	3839.832	3
3463.286	3	3617.100	3	3730.737	3	3850.561	3
3467.192	2	3619.348	3	3731.048	1	3852.260	2
3473.892	9	3620.434	2	3732.170	2 [2]	3857.680	4
3481.449	4	3625.339	4	3733.188	2	3862.819	4
3483.317	3	3626.886	4 [2]	3737.540	3	3865.547	3
3483.438	3	3627.433	2	3737.902	2	3867.962	3
3494.404	3	3631.859	3	3738.773	2	3873.660	3
3496.131	3	3634 064	3	3739.057	2	3876.229	1
3496.272	2	3635.084	12 r	3739.610	4	3884.207	2
3498.086	2	3635.658	2	3742.422	10 r	3884.849	2
3499.095	35 r	3637.612	3	3742.933	7	3887.960	2
3513.799	3	3638.161	2	3744.363	3	3890.347	3
3514.631	5	3640.786	3	3753.684	4	3891.564	2
3519.785	4	3646.262	3	3755.234	3	3892.364	5
3520.286	4	3650.465	3	3755.868	2	3892.915	1
3528.832	4	3652.460	2	3756.075	5	3897.383	2
3531.543	4	3654.549	4	3759.979	7	3898.498	2
3532.962	4	3660.961	2	3760.163	10 r	3901.391	3
3535.537	3	3661.525	10 r	3761.655	3	3908.906	2
3535.988	4	3661.721	2	3764.173	2 [2]	3909.222	5
3538.100	4	3663.520	6	3767.495	4	3912.252	2
3539.415	2	3669.688	6 [3]	3773.314	2	3914.990	3
3539.521	3	3671.355	2	3777.729	4	3920.060	4
3541.777	4	3672.521	2	3778.853	2	3923.615	6
3547.131	2	3675.400	1	3786.194	10 r	3924.774	2
3550.419	3	3676.808	2	3790.655	12 r	3926.062	6
3553.998	2	3677.098	1	3795.052	2	3931.920	5
3556.773	2	3678.456	4	3795.316	2	3933.700	4
3557.207	2	3686.086	2	3798.189	3	3938.060	3
3562.043	2	3693.734	2 [2]	3799.042	15 r	3941.819	2
3564.509	2	3696.725	4	3799.489	15 r	3942.215	3
3564.719	2	3697.906	2	3800.393	3	3944.339	2
3564.949	2	3701.456	2	3803.326	3	3945.730	4
3567.309	2	3702.369	2	3805.570	2 [2]	3946.468	2
3570.748	4	3703.343	2	3808.824	3	3949.560	7
3571.913	2	3705.496	2 [2]	3812.869	2	3950.183	3
3574.748	3	3712.444	3	3814.976	3 [2]	3950.371	4
3579.924	2	3715.705	3	3817.424	3	3950.556	3
3584.349	1	3716.314	3	3819.173	2	3951.360	2
3589.360	7	3717.146	4	3822.233	3	3952.844	4

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[1] Distinct from Rh 3462.184.

[2] Not certainly due to Ruthenium.

[3] Also Fe.

RUTHENIUM.—*Continued.*

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
3957.600	2	4100.530	2	4226.824	2	4361.371	7
3965.055	4	4102.443	2	4229.475	3	4361.597	2
3974.650	2	4108.001	3	4230.478	5	4371.366	3
3978.600	5	4108.224	2	4232.481	3	4372.363	6
3979.571	5	4112.905	10	4236.834	3	4383.526	3
3985.007	6	4113.542	3	4241.215	6	4385.553	5
3987.942	5	4118.666	2	4243.216	7	4385.814	5
3996.128	4	4121.153	3	4244.992	4	4386.436	3
4005.793	3	4123.227	3	4246.498	3	4390.605	6
4006.748	2	4127.609	2	4246.893	4	4391.191	3
4007.686	2	4128.035	2	4259.144	5	4397.966	4
4008.418	2	4137.394	3	4265.762	2	4410.193	6
4013.652	2	4144.324	7	4277.413	2	4421.013	2
4022.315	5	4145.905	5	4278.844	2	4421.626	3
4023.986	5	4146.939	4	4282.089	2	4428.631	4
4024.847	2	4148.539	2	4282.367	3	4439.935	4
4031.155	2	4150.470	2	4284.490	6	4444.681	2
4032.362	3	4161.823	3	4287.204	4	4449.509	4
4039.365	4	4167.047	2	4293.443	4	4460.194	5
4045.949	4	4167.683	4	4294.948	4	4474.100	3
4049.570	2	4170.219	2	4296.090	4	4480.617	3
4051.561	6	4175.604	1	4297.870	10	4498.316	4
4052.354	3	4182.623	2	4307.746	6	4510.265	3
4054.212	4	4182.812	2	4314.471	3	4511.364	2
4063.023	2	4182.998	1	4316.801	2	4517.063	3
4063.147	3	4189.631	2	4318.599	4	4517.985	3
4064.263	2	4197.039	3	4320.036	5	4521.124	3
4064.615	3	4197.745	4	4325.213	4	4547.467	3
4067.771	3	4199.039	4	4326.986	4	4548.031	3
4068.529	4	4200.062	16 r	4327.590	3	4550.121	2
4071.561	2	4206.178	5	4331.329	3	4552.293	2
4073.156	3	4207.798	2	4336.591	2	4554.697	13 r
4076.886	5	4212.225	10	4337.431	4	4560.168	2
4080.757	15 r	4214.604	4	4342.236	5	4584.619	4
4085.589	3	4214.714	2	4346.645	3	4591.285	2
4091.223	3	4217.427	4	4349.867	4	4592.699	2
4097.185	3	4220.838	3	4354.296	5	4599.265	3
4097.948	6	4225.256	3	4354.969	3		

PALLADIUM.

(*W.-l. 3000 to 4200.*)

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
3002.765	6	3373.139	30 r	3481.300	40 r	3662.520	4 n[1]
3028.021	9 r	3380.832	4	3486.112	2	3690.483	25 r
3065.408	9 r	3389.195	3	3489.915	20 r	3719.046	15 r[1]
3114.152	20 r	3404.725	100 r	3517.096	50 r	3799.335	10 r
3142.927	5	3406.196	3	3528.878	3	3894.334	25
3219.097	5	3419.805	5	3553.236	45 r	3958.772	25
3242.828	60 r	3421.367	50 r	3566.781	3	4087.513	10 s
3251.760	20 r	3433.578	30 r	3571.302	20 r	4170.006	6
3258.900	25 r	3441.539	25 r	3596.804	3	4213.115	15
3287.377	7	3442.548	3	3609.696	65 r	4473.761	10 s
3302.256	30 r	3460.884	35 r	3634.841	65 r		

[1] Not certainly due to Palladium.

MINOR CONTRIBUTIONS AND NOTES.

NOTE ON THE RESULTS OF MESSRS. JEWELL, HUMPHREYS AND MOHLER.

THE very important investigations by Messrs. Jewell, Humphreys and Mohler promise to lead to most valuable results, but I should like to point out that on one point further experimental investigation is desirable, before a complete application of the discovered facts can be made. The question which forces itself upon me is this:

Is the displacement of the lines due to pressure only, *i. e.*, to molecular impact, or is it due to the proximity of molecules vibrating in equal periods? The latter seems the more probable explanation—but if it is the true one it would follow that the displacement would not take place—or not to the same extent if the pressure is produced by molecules of a different kind to those under examination. It seems important to ascertain for this reason whether the shifting, say of the cadmium lines, is the same whether pure cadmium is introduced into the arc or whether an alloy is taken containing a small quantity of cadmium only.

I am induced to make this suggestion as I am reminded of some former observations which I have described in a lecture at the Royal Institution of Great Britain in 1881, and from which I drew the following conclusion:

"Placing a molecule in an atmosphere of a different nature—without change of temperature—produces the same effect as would be observed in lowering the temperature."

Something similar seems to take place as regards pressure, for the sodium lines may be obtained wide or narrow according as the atmosphere producing the pressure consists of sodium molecules only, or of molecules of a different nature. It is to be hoped therefore that Messrs. Humphreys and Mohler will complete their investigations as regards this important point, because the applications of the fact discovered by Mr. Jewell would in some conceivable cases materially depend on the answer to the question which I have raised.

ARTHUR SCHUSTER.

NOTE ON THE USE OF CYLINDER OILS FOR REFLECTING SURFACES.

OWING to the increased vibrations incident to city traffic in the shape of electric and cable car lines, mercury had to be given up as a reflecting surface for sextant and other work at the Johns Hopkins University. Molasses, which was substituted, while giving a good surface at first, soon became "cooked" in the Sun's rays and was useless. Hoping to find a better substitute, samples of oils were secured through the courtesy of the Johns Hopkins Oil Co. The first experiments were made with the temperature of the air varying from 70° to 45° (F.) and were continued as the weather grew colder, to 10°.

The oils used were:

Black cylinder, 40° cold test—too heavy; distorted image.

Black oil, 15° cold test—too heavy; distorted image.

Light filtered cylinder stock, 40° cold test—too transparent; gave halos.

Medium dark cylinder stock, 40° cold test, 26 density. This oil gave a remarkably bright surface, free from all vibration. The reflected image was so sharp that the details of some Sun-spots could be made out equally as well as in the direct image. Below 45° a film of irregularly shaped plates formed on the surface and destroyed its reflecting power. An oil known as locomotive cylinder oil, 0° cold test, was then substituted and gave equally good results down to the lowest temperature tried. At higher temperatures this oil became very fluid, but continued to give a remarkably bright reflected image without vibration.

Cottonseed and lard oils mixed with lampblack gave good results at medium temperatures, but it was difficult to keep the lampblack in suspension. I am informed that locomotive oils similar to the 0° test one experimented on can be furnished with almost any degree of cold test, which would make it possible to use it in any climate. A wind screen is necessary, as the oil surface is more readily affected than mercury by air currents.

The advantages of oil over mercury are that it is freer from vibration, cheaper, lighter to carry and easier to obtain in out-of-the-way places, as any locomotive engineer can supply oil suitable for the temperature of the neighborhood. SAMUEL V. HOFFMAN.

JOHNS HOPKINS UNIVERSITY,
February 26, 1896.

RÖNTGEN'S X RAYS.

Up to the beginning of this present year there were known only two radiations which were produced by a Crookes tube through which a discharge was passing: light vibrations and kathode rays. In January of this year Professor Röntgen, of the University of Würzburg, announced the fact that he had discovered a radiation which seemed to have no connection with the two others previously known.

The history of this discovery is well known to everyone, and so are the many applications of the method to surgery and other branches of science. It may be useful, however, to give a summary of the properties of the X rays, and to compare them with those of light and kathode rays.

It may first be stated that all three radiations have certain points in common; they pass out of the Crookes tube if it is thin enough; they move in straight lines, if uninfluenced; they produce fluorescence in certain bodies, which are not the same, however, for all three; they pass through various objects, although the relative transparency of various objects differs for them all; they all influence photographic plates.

Light vibrations have certain individual properties: they can be reflected, refracted, diffracted, and polarized; they can therefore be focused, and can also produce interference. Neither kathode rays nor X rays have, so far as now known, any of these properties.

Kathode rays are radiations which leave the kathode of a Crookes tube through which a discharge is passing, and which also seem to start from other points in the tube which may be called secondary kathodes. Their properties are now well known, owing to the investigations of Crookes, Hertz, Lenard and Perrin. Although they can emerge from the tube under certain conditions, they cannot pass far into the open air, behaving a good deal like light in a turbid medium. Further, the direction of their path may be changed by bringing a magnet near. This last property is peculiar to kathode rays so far as now known.

X rays seem to be entirely unaffected by magnets, and also to obey none of the ordinary laws of light; further, they can pass many feet away from the tube, their intensity, however, decreasing as the inverse square of the distance. The exact source of the X rays is not known at present. M. Moreau and M. de Heen in France have announced that ıey proceed from the anode in the Crookes tube. Professor H. A. .owland of Johns Hopkins University thinks that the tube which he as so far used emits the rays direct from the anode; but his tube is ne where the anode and kathode are only 1^{mm} apart, so that the ‹periment is not conclusive. Mr. Elihu Thomson has shown that in is tube the rays are certainly emitted by the kathode. Röntgen, imself, believed that the rays came from the surface of the glass tube hich was rendered fluorescent by the kathode rays; and although this ıeory has been supported by many experiments, it seems to be incorct, as it is absolutely at variance with several well-known experiments. ne of the most interesting properties of the X rays was discovered ' Professor J. J. Thomson of Cambridge. It is the fact that any electric through which these rays are passing becomes a conductor r electricity. He has further shown that, in every way, such a medium, *g.*, air, behaves exactly as if it were an electrolyte, being made so by nization.

As to the theory of these various radiations from the Crookes be, something definite is known about light vibrations and kathode .ys, but not about the X rays. Light vibrations are transverse ones the ether. Kathode rays are undoubtedly streams of negatively ıarged portions of ordinary matter. This is almost positively proved ' the recent work of M. Jean Perrin; and so Hertz' theory seems to be ·roneous and that of Crookes and J. J. Thomson correct. For all we ıow now X rays may be either transverse or longitudinal waves in the her, or they may be streams of rapidly moving matter. This last ʏpothesis seems at this moment to be most probable.

It may be well to note that there are two methods which may be ›ed to study the X rays. One is by photography; the other is by eans of their fluorescent action. A tube is made of opaque cardboard ith a single aperture at one end, and having the other end closed ith an opaque diaphragm. On the inner side of this diphragm is aced a piece of blotting paper impregnated with barium-platinoanide in the crystalline state. If this tube is now pointed at a rookes tube emitting X rays, the eye of the observer being at the ›erture, it will be seen that the platinum salt fluoresces beautifully. obstacles are placed between the tube and the fluorescent diaphragm ıadows will of course be cast. Another most interesting fact is that hen phosphorescent zinc sulphide is coated over an opaque metal, it akes it transparent to these rays.

J. S. A.

HARVARD COLLEGE OBSERVATORY, CIRCULAR NO. 6

NEW VARIABLE STARS.

An examination of the Henry Draper Memorial photographs of stellar spectra by Mrs. Fleming has led to the discovery of fourteen new variable stars of long period, in addition to those previously announced. The spectrum of the fifth star in the following list is of the fourth type. All of the others have spectra of the third type having also the hydrogen lines bright, and it was this peculiarity which led to their discovery. The variability has been shown by comparison of a large number of photographs, and the variation has been confirmed in each case by the writer. The following table gives the constellation, the catalogue designation of the star, the approximate right ascension and declination for 1900, the number of plates examined, the photographic magnitude, when brightest and faintest as derived from these plates, and the epoch and period as obtained from the material now available. The epoch is expressed in Julian Days omitting the constant 2,410,000. It is needless to caution astronomers, that these elements cannot safely be used to predict future maxima with accuracy. They generally represent the photographic magnitudes during the last eight years, with an average deviation of one or two tenths of a unit. As, however, the periods and light curves in many cases change, the true law can be determined only from long series of observations. The date of the next maximum, as indicated by the formula, is given in the final column.

Constellation	Designation	R. A. 1900	Dec. 1900	No. Plates	Magn.		Epoch	Period	Maximum 1896
					Br.	Ft.			
Sculptor	−39° 16	$0^h\ 3^m.6$	−39° 47′	43	8.9	<12.1	165	295	May 25
Columba	*A.G.C.* 6135	5 15 .6	−33 48	24	7.6	11.3	134	225	June 23
Canis Minor	....	7 1 .5	+9 1	40	10.3	<13.7	174	364	Sept. 11
Virgo	+5° 2708	12 57 .6	+5 43	51	8.8	9.7	...	...	....
Apus	....	14 59 .3	−71 40	58	9.0	<11.4	...	...	....
Sagittarius	−33° 13234	18 21 .4	−33 23	48	8.2	12.3	267	316	July 2
Sagittarius	−19° 5347	19 8 .1	−19 2	47	9.7	11.1	...	...	....
Sagittarius	....	19 8 .7	−18 59	48	9.9	<13.3	...	...	....
Pavo	....	19 39 .5	−72 1	66	7.6	12.1	156	243	Aug. 29
Microscopium	*A.G.C.* 28038	20 21 .8	−28 35	49	7.4	8.4	...	...	....
Pavo	....	20 47 .2	−63 5	43	9.6	<12.3	...	...	....
Grus	−38° 15044	22 19 .9	−38 4	57	8.6	11.0	...	...	....
Grus	....	22 19 .9	−48 57	48	7.2	12.3	90	400	May 10
Aquarius	−16° 6379	23 47 .1	−16 25	42	8.2	9.3	...	...	....

The third of these stars is near the border of Monoceros.

— 33° 13234 was suspected of variability by Dr. Thome (*Annals Cordoba Observatory*, Vol. XVII, page xiii).

A. G. C. 28038 is in Sagittarius according to the *Uranometria Nova* and Heis.

EDWARD C. PICKERING.

March 10, 1896.

The dates and corresponding magnitudes for the variable stars given in the above circular are here appended. When the object is not a catalogue star the position determined from a photographic chart is inserted.

—Sculptoris. —39° 16. The magnitudes of this star, as derived from photographs taken on September 2, September 6, September 6, October 1, October 8, October 28, October 29, November 27, 1889; September 8, September 15, 1890; August 9, August 20, August 28, September 17, September 17, October 2, October 25, 1891; July 12, August 5, September 26, 1892; July 22, August 19, August 21, August 21, September 11, September 16, September 27, October 28, November 1, 1893; August 14, August 24, August 25, September 11, October 19, November 10, November 12, 1894; July 10, July 19, August 1, August 3, August 14, September 11, and September 21, 1895, are <12.1, 11.64?, <11.2, <9.1, <10.7, <10.8, <10.3, <9.0; 9.64, 9.50; <9.1, 9.33, <9.3, 11.28; <10.7, <8.7, <8.5; 11.23, <9.4, <9.6; <9.3, <9.7, <11.8, <11.8, <9.0, <9.0, <11.8, 11.13, <9.3; 11.03, <9.2, <8.5, 9.64, 8.93, 9.26, 9.26; 10.82, 9.81, 9.23, 9.23, 9.52, 9.64, and <9.1 respectively.

—Columbae. *A. G. C.* 6135. The magnitudes of this star, as derived from photographs taken on October 8, October 10, October 10, November 13, 1889; September 24, 1890; November 7, December 2, 1891; August 12, September 28, 1892; March 8, September 27, November 18, 1893; September 19, November 5, November 10, November 19, November 26, December 13, December 14, 1894; September 7, September 10, September 19, September 20, and October 5, 1895, are 7.71, 8.25, 7.71, 8.92; <8.4; 10.66, <8.6; 9.23, 7.59; <8.8, 11.26, 9.43; 8.58, <8.7, 10.17, 10.61, <8.4, 11.22, 11.08; 9.53, 9.48, 8.92, 8.86, and 8.56 respectively.

—Canis Minoris. R. A. $6^h\ 59^m\ 5^s$ Dec. $+ 9° \ 5'.4$ (1855). The magnitudes of this star, as derived from photographs taken on January 16, January 21, 1888; November 14, 1889; February 6, 1890; January 26, February 22, December 10, December 10, 1891; January 20, February 5, February 6, February 12, February 13, February 18, March 13, 1892; January 19, February 4, February 5, February 15, March 16, November 1, November 24, December 26, December 27, 1893; March 2, March 16, March 24, April 18, October 31, November 6, November 25, November 28, 1894; January 22, February 26, March 30, October 5, October 22, October 24, October 29, and November 12, 1895, are <9.2, <9.9; 11.24; <13.0; <10.9, <13.3, 12.13, <11.2; 13.50, <13.2, <12.8, <11.9, <13.0, <13.3, <13.7; <12.4, 13.55, <13.5, <13.6, <11.3, <10.8, 11.22, <13.7, <11.8; <10.3, <11.9, <11.8, <13.7, <10.3, <9.9, <10.1, <10.0; <10.7, <10.7, <10.3, 10.27, 10.42, 10.63, 10.58, and 11.05 respectively.

—Virginis. + 5° 2708. The magnitudes of this star, as derived from photographs taken on April 10, 1886; January 13, February 6, April 7, April 16, April 22, April 25, May 12, December 14, December 22, 1890; January 8, March 1, April 24, May 23, May 25, May 28, 1891; January 21, February 4, February 9, February 17, March 20, April 20, April 25, May 13, May 13, May 27, 1892; January 25, April 19, May 9, May 17, May 31, May 31, June 12. June 14, June 29, June 29, 1893; January 19, February 26, May 3, May 14, May 21, May 22, 1894; May 9, May 10, May 10, May 11, May 22, June 6, July 3, July 3, and July 9, 1895, are 9.15; 9.00, 9.10, 9.05, 9.33, 9.33, 9.55, 9.50, 9.20, 9.30; 9.20, 9.05, 9.40, 9.10, 9.27, 9.33; 9.20, 9.20, 9.65, 9.20, 8.95, 9.10, 8.95, 8.90, 8.80, 9.00; 9.05, 8.80, 9.70, 9.20, 8.80, 9.08, 9.20, 9.00, 9.27, 9.05; 9.42, 9.10, 9.00, 9.50, 9.23, 9.35; 9.45, 9.20, 9.36, 9.20, 9.30, 9.24, 9.00, 8.80, and 8.90 respectively.

—Apodis. R. A. 14^h 56^m 54^s Dec. — 71° 34.′4 (1875). The magnitudes of this star, as derived from photographs taken on May 31, July 7, July 8, July 9, July 9, July 12, July 12, 1889; June 12, August 2, 1890; June 16, June 16, June 19, June 19, June 27, June 27, 1891; July 24, 1892; May 1, May 1, May 2, May 2, May 2, May 4, May 4, June 23, July 26, 1893; April 18, April 21, May 3, May 14, May 14, May 17, May 17, May 17, June 20, July 7, July 13, August 1, August 9, August 13, August 13, August 14, 1894; February 22, March 5, April 3, April 6, April 8, May 6, May 6, May 7, May 9, June 1, July 8, July 16, July 17, August 2, August 10, August 12, and September 11, 1895, are 9.54, 9.49, 9.69, 9.49, 9.64, 9.59, 9.59; 10.82, <11.4; 9.44, 9.59, 9.69, 9.54, <9.4, 9.38; <9.3; 9.90, 10.00, 9.79, 9.85, 9.85, 9.85, 9.64, 9.38, 9.23; 8.99, 8.99, 9.09, 9.28, 9.28, 9.09, 8.96, 8.94, 9.23, 9.18, 8.94, <8.6, 9.64, 9.09, 8.99, 9.09; <9.0, <9.9, <8.7, 9.90, 9.59, 9.74, 9.59, 9.69, 9.59, 9.49, 9.38, 9.05, 8.79, 9.38, 9.05, 9.09, and 9.43 respectively.

—Sagittarii. −33° 13234. The magnitudes of this star, as derived from photographs taken on June 13, June 26, July 2, July 8, July 24, August 6, August 8, August 8, September 4, October 10, 1889; May 11, May 13, May 22, 1890; May 29, May 29, May 30, May 30, August 5, August 7, September 17, 1891; June 6, July 30, 1892; June 5, June 9, June 14, June 15, June 15, June 24, July 5, July 21, July 22, August 3, 1893; July 7, August 7, August 16, 1894; March 6, June 3, June 4, June 18, June 26, June 29, July 9, July 9, August 15, September 5, September 5, September 6, and September 14, 1895, are <9.8, <8.7, <8.5, 8.72, 8.33, 8.23, 8.43, 8.63, 9.24, <10.2; <8.9, <8.8, 9.18; 8.93, 8.78, 8.83, 8.93, <9.6, <8.7, <10.6; <9.2, <9.2; <9.7, <9.9, <10.1, 12.12, 12.12, 12.08, <10.6, <12.0, 12.26, <9.4; <9.6, 10.90, 10.46; <10.6, 11.40, 11.34, <10.5, <9.8, 9.68, 10.02, 10.12, 8.80, 8.53, 8.57, 8.88, and 8.98 respectively.

—Sagittarii. −19° 5347. The magnitudes of this star, as derived from photographs taken on September 5, November 7, November 11, November 11, 1888; June 29, August 16, September 7, 1889; October 30, 1890; June 1, June 1, June 9, July 15, September 7, September 18, 1891; May 25, June 1, August 18, 1892; April 30, April 30, June 7, July 17, July 31, July 31, 1893; June 27, September 25, November 13, November 13, 1894; June 3, June 4, June 14, June 14, June 18, July 2, July 10, July 10, July 12, July 15, July 21, July 23, July 27, July 30, August 14, August 16, September 7, September 13, September 16, and September 20, 1895, are <8.7, 9.77, 9.67, 9.77; <9.1, 10.58, 10.87; 10.85; 9.81, 9.77, <10.5, <10.0, <9.9, <10.0; <10.1, <9.4, 10.48; 11.12, 10.86, 9.82, <10.1, 10.11, 10.26; 10.11, 10.02, 11.06, 10.68; 10.68, 10.66, 10.65, 10.40, 10.32, 9.82, 9.91, 9.85, 9.81, 10.68, 10.06, 10.01, 9.82, 10.01, 10.21, 10.01, 10.21, 10.11, 9.92, and 10.26 respectively.

—Sagittarii. R.A. $19^h 6^m 4^s$ Dec. −19° 3′.2 (1855). The magnitudes of this star, as derived from photographs taken on September 5, November 7, November 11, November 11, 1888; June 29, August 16, September 7, 1889; October 30, 1890; June 1, June 1, June 9, July 15, September 7, September 18, 1891; May 25, May 27, June 1, August 18, 1892; April 30, April 30, June 7, July 17, July 22, July 22, July 31, 1893; June 27, September 25, November 13, November 13, 1894; June 3, June 4, June 14, June 14, June 18, July 2, July 10, July 10, July 12, July 21, July 23, July 27, July 30, August 14, August 16, September 7, September 13, September 16, and September 20, 1895, are <8.7, <11.5, <9.9, <9.9; <9.1, 12.30, <13.2; <11.0; <10.6, <12.0, <10.5, 10.02, <9.9, <10.0; <10.1, <10.2, <9.4, 13.29; 12.20, <13.3, <10.2, <10.1, <12.4, <12.4, <11.4; <10.1, 9.92, 11.46, 11.01; 12.02, 11.90, 11.72, <10.5, <11.4, <10.0, 10.01, 10.81, 10.85, <10.8, 10.68, 10.02, 10.52, 9.96, 10.16, 9.96, 10.18, <10.0, and 10.68 respectively.

—Pavonis. R.A. $19^h 36^m 40^s$, Dec. $-72° 4'.2$ (1875). The magnitudes of this star, as derived from photographs taken on June 7, June 13, June 13, July 8, July 13, August 2, August 12, August 30, 1889; May 28, May 29, 1890; June 11, June 11, June 11, June 13, June 13, June 13, August 24, August 25, August 27, August 29, September 19, 1891; June 24, July 3, 1892; May 2, May 2, May 2, May 2, May 3, June 23, August 26, August 26, October 24, 1893; July 14, July 16, July 16, July 16, July 21, July 23, July 31, July 31, August 1, August 10, August 13, August 14, August 22, September 4, September 10, September 12, November 12, 1894; April 9, April 9, April 10, May 9, May 9, May 9, May 31, June 3, June 15, June 15, July 2, July 2, July 31, August 1, August 3, September 7, and September. 15, 1895, are <9.0, 9.12, 9.12, 9.70, 9.96, 10.34, 10.61, <8.1; 12.06, <9.0; 8.38, 8.32, 8.32, 8.96, 9.06, 8.92, <9.7, <10.0, 9.91, <9.9, <10.3; <10.0, <10.4; 7.98, 7.73, 7.73, 7.89, 7.58, 10.34, 11.01, <10.5, <10.9; 11.70, <10.6, 11.62, <10.7, 11.18, <9.7, <9.3, <9.3, <9.3, <11.4, 10.14, 10.06, 9.43, 10.24, 9.12, 10.38, 10.11; 9.50, 9.60, 9.41, 8.23 8.27, 8.02, 8.62, 8.68, 9.33, 9.43, 9.84, 9.73, 10.46, 10.84, <10.4, 11.76, and <9.9 respectively.

—Microscopii. *A.G.C.* 28038. The magnitudes of this star, as derived from photographs taken on July 17, 1888; June 10, July 1, July 2, July 8, August 2, August 5, August 22, September 9, September 20, October 7, 1889; May 14, May 24, June 7, 1890; May 30, May 30, July 16, 1891; June 11, June 13, September 23, 1892; April 30, April 30, July 14, July 17, July 19, July 21, July 21, July 21, August 4, 1893; April 19, April 30, August 11, August 21, October 1, November 12, 1894; April 25, May 10, June 1, June 4, June 6, June 6, June 14, June 27, July 2, August 20, September 6, September 6, September 20, and October 14, 1895, are 7.94; 7.90, <7.9, <8.0, 7.74, 7.80, 7.94, 7.70, <8.2, 7.54, 7.74; 7.94, 8.00, <8.4; 7.94, 8.15, 7.94; 8.00, 8.00, 8.02; 7.92, 7.80, 7.90, 7.90, 8.00, 8.00, 7.67, 7.94, 7.80; 8.18, 8.10, 7.61, 7.80, 8.15, 8.15; 8.31, 8.36, 8.38, 7.94, 7.94, 7.70, 7.84, 7.82, 7.43, 7.90, 8.04, 8.15, 7.94, and 8.15 respectively.

—Pavonis. R. A. 20^h 45^m 4^s, Dec. -63° 10′.7 (1875). The magnitudes of this star, as derived from photographs taken on June 17, July 13, August 16, 1889; September 8, 1890; June 10, June 10, June 10, June 11, June 11, August 19, 1891; June 23, June 23, August 17, September 8, September 8, September 8, September 26, 1892; August 5, August 26, August 26, October 24, October 24, 1893; July 2, July 6, July 9, July 10, July 10, July 14, July 16, August 1, August 10, August 23, September 4, September 15, September 22, 1894; May 9, May 9, May 31, June 3, June 15, July 10, July 31, and August 1, 1895, are <12.0, <10.9, 11.78; <9.3; 10.14, 9.97, 10.31, 10.12, 10.31, <8.9; <8.9, <8.4, <9.8, <12.2, <12.2, <11.3, <10.4; <9.8, <10.5, 11.98, 9.62, 9.77; <9.4, <8.9, <9.8, <10.4, <10.3, <12.3, <11.2, <9.0, 10.62, 9.58, <9.8, 10.02, <9.1; 11.99, 11.84, <9.1, <9.8, 9.60, 9.82, 9.92, and 10.02 respectively.

—Gruis. -38° 15044. The magnitudes of this star, as derived from photographs taken on July 17, July 19, July 22, August 5, August 18, August 19, August 21, September 11, September 30, October 8, 1889; June 12, July 22, September 9, September 15, September 19, October 1, October 2, October 3, 1890; June 14, June 14, July 2, July 18, August 1, August 1, August 6, August 7, August 18, September 6, September 29, October 2, 1891; June 25, July 30, August 23, September 16, 1892; July 12, July 17, July 24, July 27, July 27, July 27, September 15, September 27, September 27, 1893; May 22, May 23, July 14, August 7, August 11, September 27, September 29, 1894; June 7, June 8, June 29, July 3, August 1, October 5, and October 12, 1895, are 8.76, 8.80, 8.76, 8.95, <8.7, <8.5, 9.28, 10.46, <10.0, <10.2; 10.39, <8.4, 8.76, <8.7, 9.13, <8.5, <8.7, <8.6; 8.86, 8.70, <8.7, <9.1, 11.04, 10.73, <9.0, <8.4, <10.8, <9.0, 8.86, 8.96; <8.8, 8.68, 9.44, <8.6; <9.0, 9.03, 9.65, 8.95, 8.95, 9.13, 8.70, 9.47, 9.40; 8.56, 8.80, 10.66, <8.8, 11.00, 8.86, 8.76; 9.37, 9.40, 8.66, 8.68, 8.95, 11.04, and <8.9 respectively.

—Gruis. R.A. 22^h 18^m 22^s, Dec. -49° 4′.4 (1875). The magnitudes of this star, as derived from photographs taken on July 5, July 8, July 13, July 18, July 22, August 3, August 3, August 20, September 11, September 28, September 30, October 10, 1889; May 29, June 10, July 21, July 21, September 12, 1890; June 13, June 13, July 9, August 9, August 10, 1891; August 4, 1892; July 12, July 12, July 27, September

16, September 27, September 27, 1893; May 21, May 22, July 14, July 16, July 30, August 11, September 26, November 5, 1894; May 9, July 3, July 16, July 31, August 1, August 1, August 13, August 20, August 20, October 24, and November 11, 1895, are <11.9, <11.1, <11.4, 11.58, <10.9, 8.73?, <8.4, 11.06, 10.66, <10.1, 10.03, 8.71; <8.5, <12.1, <8.3, <8.3, <8.5; <10.7, <11.5, <9.3, <8.4, <8.8; <9.0; <9.8, <9.4, 10.70, <9.8, 12.26, <12.0; 8.62, 8.42, 9.95, 9.80, <9.0, 10.29, <9.3, <9.8; 7.17, 8.47, 9.03, 8.94, 9.15, 9.70, 9.70, <9.8, <8.9, 10.86, and <9.5 respectively.

—Aquarii. −16° 6379. The magnitudes of this star, as derived from photographs taken on January 21, October 31, November 13, 1888; September 6, September 7, December 7, December 7, December 9, December 16, December 28, 1889; July 9, July 11, September 8, September 24, October 12, 1890; August 1, August 13, August 13, August 27, 1891; July 29, September 26, 1892; June 28, June 28, August 7, August 19, September 20, October 3, October 13, October 13, October 17, 1893; September 27, November 13, November 16, November 16, December 13, December 20, 1894; January 2, July 3, July 27, August 3, September 13, and October 18, 1895, are 8.54, 8.67, 9.24; 9.10, 9.10, 9.04, 9.24, 9.20, 9.30, 9.30; 8.34, 8.44, 9.14, 9.10, 9.30; 8.60, 8.54, 8.42, 8.34; 8.94, 8.44; 8.40, 8.52, 8.80, 8.70, 9.04, <8.3, 8.94, 8.70, 8.64; 8.80, 9.00, 9.14, 9.14, 8.37, 8.44; 8.64, 8.60, 9.04, 9.04, 8.15, and 8.64 respectively.

REVIEWS.

On the Newtonian Constant of Gravitation. C. V. BOYS. *Phil. Trans.* **186,** A., 1–72 (1895).

Since the discovery and enunciation of the law of gravitation a little more than two centuries ago, the problem of accurately determining G, the Newtonian constant of gravitation has been one which has occupied the attention of many of our most eminent physicists and astronomers. In this memoir Professor Boys has described in full his own work on the measurement of this important physical constant, which extended over a period of nearly six years, and which we may safely say has for the first time given us a value whose accuracy is comparable with the results attained in our other physical measurements.

The paper is divided into three parts. Part I. opens with a general discussion of the method, followed by a minute and carefully written description of the apparatus. This, we may remark in passing, is a plan which could be followed with advantage by many of our English and American writers who as a class are careless or indifferent in this matter. In this day of rapid progress in physical measurement every one must expect his work to be sooner or later surpassed in accuracy by the determinations of others, and the more completely and carefully his own methods of work and his experiments, be they failures or successes, are described, the greater will be the benefit which he will ultimately render to science by enabling those who follow to avoid the difficulties which he has encountered. The method of experimentation was that originally devised by Mitchell, but which having been first carried out by Cavendish is generally known by his name. This method, which is too well known to need description, has also been used by Reich, Baily, Cornu and Baille as well as by Professor Boys. The latter's apparatus however differs radically from that of all of his predecessors in one important particular, that of size, being only about $\frac{1}{70}$ as large as the original apparatus of Cavendish and about $\frac{1}{20}$ the size employed by Cornu. In an earlier paper (*Proc. R. Soc.*, **46,** 253, June 1889), Professor Boys had discussed the theory of the apparatus and had shown that under proper conditions this decrease in size would greatly increase both the accuracy and sensitiveness of the instrument. The argument is briefly this: For a given time of swing the sensibility is independent of the linear dimensions of the apparatus. But if under this condition, that of constant period, the size of the attracting and attracted masses and their relative positions with respect to each other remain constant, while the length of the beam carrying the latter (and hence the other linear dimensions of the apparatus) is decreased, the sensibility will be augmented in an inverse ratio. The practical limit to reduction in size is determined by two considerations, the first and most important of which is the difficulty of finding a torsion thread fine enough to give the required period and at the same time strong enough to carry the suspended system. Previous to Professor Boys' beautiful invention of the quartz fiber this difficulty had prevented the use of a beam less than about ½^{m} in length; with these fibers it was found practicable to reduce the length of the beam to less than 2^{cm} while retaining a period of five minutes or more. The second difficulty consequent upon a reduction in the length of the beam is the increased equality of the effect of each attracting mass on the two attracted masses at the opposite ends of the beam. This difficulty is ingeniously avoided by Professor Boys by placing the attracting masses on the two sides at different levels. In addition to increased sensitiveness the smaller instrument allows several other important advantages to be attained, among which may be mentioned the following: (1) A symmetrical arrangement of parts about the axis of rotation, eliminating at once the troublesome corrections for the gravitational attraction of the case, etc. (2) More perfect protection against temperature changes by the use of a system of concentric screens. (3) More rapid equalization of the small temperature changes which do occur and a consequent diminution of the effect of convection currents which are "the last and the most difficult to avoid, and set the limit to the accuracy which is obtainable in this experiment;" and last but not least, the more convenient manipulation of the instrument.

In an instrument for absolute measurement, however, the reduction in size cannot be carried beyond a certain limit without diminishing the accuracy of the necessary measurements of the geometrical dimensions, and it was therefore deemed best to adopt for the final experiments a size somewhat larger than that with which the preliminary experiments were made. The principal dimensions finally adopted were:

(1) Horizontal distance between centers of attracting masses, 6 inches or 4 inches.
(2) Horizontal distance between pair of attracted masses, 0.9 inch.
(3) Vertical distance between centers of masses on the two sides, 6 inches.
(4) Diameters of large attracting masses (spheres), 4½ inches or 2¼ inches.
(5) Diameters of small attracted masses (spheres), 0.2 inch or 0.25 inch.

The degree of accuracy aimed at in the determination was 1 part in 10,000. This involves a determination of the principal geometrical dimensions of the apparatus to 1 part in 10,000 and of the times to 1 part in 20,000. Of the geometrical dimensions the quantities (1) and (2) are two of the most important. In order to readily measure them with the required degree of accuracy a very ingenious and original plan of suspension was adopted. Each of the masses was hung from a fine fiber (phosphor bronze, in case of the large masses, quartz in case of the small). The distance between the centers of the fibers was then necessarily the distance between the centers of gravity of the suspended masses, and the instrument was so arranged that these distances could be accurately measured by a specially designed comparator, or optical compass, when the whole system was in position. This last instrument deserves special mention on account of its admirable geometrical design and its usefulness for other purposes.

The large masses were spherical balls of lead formed in cast iron moulds, by a process which at the same time secured truth of form and homogeneity of structure. It would seem that this result might be more easily and satisfactorily accomplished by the use of hollow globes filled with mercury, such as M. Cornu has employed. If the magnetic effect of an iron globe should prove objectionable, the globe might be made of glass or perhaps preferably of pure copper, deposited on a spherical mould by the Elmore process. The small attracted masses were gold spheres formed in steel moulds in a similar manner to that employed for the larger masses. These gold balls were suspended by quartz fibers from the ends of a beam mirror which was constructed by Professor Boys himself, and which is therefore, it is scarcely necessary to say, a model of the most exact and beautiful design and workmanship. It is so constructed that the mirror serves at the same time as a support by which the gold balls are kept in a definite position, and as a mirror by which their deflections can be accurately read. The mirror itself, instead of being left circular, was cut down to the form of a bar ¼ in. wide and about 0.9 in. long, by which means its moment of inertia was reduced nearly ⅔ while the horizontal definition was actually improved. This same plan could be adopted with advantage in galvanometers, magnetometers, etc. The horizontal definition was sufficiently good to enable readings to be made on the scale to $0''.7$ or about ⅓ the theoretical resolving power of the mirror. The explanation of this apparent discrepancy from theory is ascribed by Professor Boys to the effect of diffraction, which in the case of the scale which was used (one having black lines on a luminous ground), has the effect of making the images of the lines narrower than would be the case with the reverse arrangement, that of luminous lines on a black ground. While this no doubt conduces to greater accuracy of reading, it is not the full explanation of the point in question, which is to be found in the fact that the accuracy with which the position of any line may be determined depends on the width of the image in comparison with the cross-wire of the observing eyepiece. When the image is sufficiently broad and at the same time sufficiently bright, the *accuracy of locating the position* may be even 100 times as great as the theoretical resolving power of the instrument. This is also the explanation of the fact, also noted by Professor Boys, that better results are secured by making the lines themselves rather broader than would at first sight seem desirable.

The gold balls were hung from hooks on the beam mirror and so arranged that they could be readily attached or removed, after the manner of a rider on a balance beam, so that the moment of inertia of the beam itself and the torsional rigidity of the fiber could be readily determined by taking the periods with and without the suspended balls. In order that the fiber might be under the same conditions in the two cases a small silver cylinder of exactly the same weight as the two balls and their suspensions, and of known moment of inertia, was hung on the lower end of the fiber when the balls were removed. The necessity of this precaution is evidenced by the fact that a change of 2.6 grams in the mass of the suspended system changed the torsional rigidity of the fiber nearly 5 per cent. This change is much larger than could be accounted for by the elongation of the fiber alone, and is worthy of further study in connection with the theory of elasticity. In the suspension of both the gold balls and the counterweight the greatest care was taken to avoid a change in the position of the axis of rotation. The effect of such a small change as well as the small displacements of the gold balls due, to their rotational mobility, to the attraction of the large masses, and to the centrifugal force developed by the rotation of the system is fully discussed and taken account of in the reduction wherever necessary. It is hardly necessary to add that the same care in design and careful attention to detail characterizes every other part of the apparatus.

Part II. deals with the method and order of making the various measurements involved in the absolute determination of G. The number of separate operations or measurements is fourteen, but these may for the purpose of review be more conveniently divided into three groups, comprising respectively, (1) measurements of mass, (2) measurements of length, (3) measurements of time.

The measurements of mass having been made as usual with a balance, in terms of the units of the Standards Office, are of course well within the limits of accuracy imposed. The only uncertainty in this connection is as to the uniformity of the attracting masses in density, but the error due to this cause must have been exceedingly small. It could have been eliminated if present by setting each of the attracting masses in rotation about its axis of suspension during the observations of deflection.

The measurements of length include (*a*), the measurements of the geometrical dimensions of the apparatus, and (*b*) the measurements of deflection. The measurements of the geometrical dimensions, of which the principal ones were noted above, were all (with the possible exception of the distances between the centers of the gold balls and some of the dimensions of the beam mirror), within the limit of accuracy imposed, *i. e.*, 1 part in 10,000. They were determined in terms of a glass scale made by Zeiss and carefully calibrated on a standard Whitworth measuring machine. In connection with these measurements a rather curious omission on the part of the author may be noticed. Nowhere have I been able to find any mention of a correction to the measured lengths for a change in temperature. A change of 10° would cause a change of about 1 part in 10,000 in the distance between the gold balls, and 1 part in 5000 in the distance between the lead balls. Generally three days were allowed to elapse between making the linear measurements and taking the deflections and periods, and during this interval it seems possible that a change of this amount might have occurred. Undoubtedly it has been taken account of in the reductions wherever necessary.

The measurements of deflection (which were made by the ordinary scale and telescope method), are less accurate; indeed of all the measurements involved in the determination these are perhaps the most uncertain. The errors arise chiefly from actual or apparent changes in the point of rest caused: (1) By errors in reading elongations. (2) Air currents in the instrument. (3) Vibrations due to external disturbances. The elongations were read as a rule to $\frac{1}{10}$ div. so that the error due to this cause was as a rule not more than $\frac{1}{20}$ div. for each determination, and not more than $\frac{1}{50}$ div. in a mean of five or six readings. Variations due to the second two causes were more serious, amounting sometimes to as much as $\frac{1}{8}$ of a division in individual determinations, and to about $\frac{1}{10}$ of a division in a set of five. The double deflection in most of the experiments was about 370 div.; the error in the determination of this quantity varied therefore from 1 part in 4000 to 1 part in 8000.

Time Measurements.—The observations of period from which the moment of inertia of the moving system and the torsional rigidity of the fiber were deduced were taken by the chronographic method, the time record being furnished by a standard astronomical clock by Frodsham. The same causes of error which render the observations of deflection inaccurate affect these observations also, and to about the same degree. The average error in the determination of the period would appear to be about $0^{\text{sec}}.01$, or 1 part in 10,000. Since the squares of the period enter in the calculation of G, the effect of this error on the final result is about 1 part in 5000.

The units of measurement employed throughout were the inch as the standard of length, the gram as the standard of mass, and the second as the standard of time. The use of this mixed system was rendered expedient by the fact that the lengths used were more easily verified in terms of the inch than in terms of the cm., a reason which is certainly not greatly to the credit of the English Standards Office, on whose recommendation it was adopted. In scientific work at least, it now ought to be possible to adhere to the system which has been universally recognized as international.

Part III. deals with the reduction of the observations and a discussion of the final results. In the reductions one point is especially worth noting, and that is that they were not carried out until long after the experiment had been performed, so that during the progress of the experiment itself there was no possibility of a personal bias arising from a knowledge of what the result of a measurement ought to have been beforehand. In all nine complete determinations were made, the conditions of experiment being varied in some way between each set. Three different pairs of small masses and three different fibers were made use of. The same pair of attracting masses was used throughout, but they were interchanged in position in almost every possible way, and the distance between their centers was also changed. The final results of the values of G were as follows:

No. of experiment	Value of G	No. of experiment	Value of G
3	6.6645 $\times 10^{-8}$	8	6.6579 $\times 10^{-8}$
4	6.6702 "	9	6.6533 "
5	6.6711 "	10	6.6578 "
6	6.6675 "	12	6.6695 "
7	6.6551 "		

An examination of these results shows that they vary from 6.653 to 6.671, or at the most by about 1 part in 300. In order to determine the most reliable values, the conditions under which the observations of period and deflection (which as already pointed out are most in error), were made, are reviewed. The first three numbers (Nos. 3, 4, 5) are all unsatisfactory; No. 3, because the arrangement for setting the system in vibration was bad, No. 4, because the observations for period were lost (they were taken to be the same as in No. 5), and No. 5, because of external disturbances. The fourth (No. 6), is considered good, as well as the fifth and sixth (Nos. 7 and 8), particularly the latter. In the seventh (No. 9), gold cylinders were substituted for the gold balls, and the increased weight of the former altered the torsional rigidity of the fiber by 5 per cent. This determination is therefore also unsatisfactory. In the eighth (No. 10), the conditions were very favorable, but in the last (No. 12), (No. 11 was a purely comparative experiment on the relative decrement of the system swinging in air and hydrogen), the conditions for taking periods were again very unfavorable.

Professor Boys concludes that experiments Nos. 7, 8, 9 and 10, of which 8 and 10 should have the greater weight, are the ones most likely to give a true value, but no reason is given why experiment No. 6 should not also be considered as equally good. The value decided upon is $G = 6.6576 \times 10^{-8}$, and it is considered that the error cannot be greater than one or two units in the fourth place. I do not quite understand how this value is obtained. If we give all of the determinations equal weight we obtain as a result

$$G = 6.6630.$$

If we give to experiments Nos. 8 and 10 a weight 4, to experiments 6, 7, and 9 a weight 2, and to all the others a weight 1 (which would seem a fair assignment of weights considering that all of the measurements except those of deflection and period were regarded as equally good in all), we obtain for G,

$$G = 6.6605 \pm 0.0014.$$

To obtain the lower value given by Boys we would either have to give experiments 7, 8, 9 and 10 very much higher weights (nearly twice as great as those assigned), or reject the first and the last observations entirely. Neither proceeding seems reasonable. Hence the value of G is uncertain to at least two places in the fourth place or to about 1 part in 3000. But this, it must be remembered, is fully ten times better than any preceding determination, and when we consider the difficulties under which the experiments were carried on, we must feel the highest admiration for the ingenuity, the manipulative skill, and the energy and perseverance of the man who has brought them to such a successful conclusion.

The paper closes with a brief discussion of the conditions necessary to secure a still higher degree of accuracy, say 1 part in 10,000, which the author still considers it possible to obtain with his apparatus.

The greatest error in the work arose, as has already been stated, from the errors in the observation of period and deflection, which are caused by air currents and external disturbances. These errors would be reduced in magnitude both by diminishing the disturbing causes;— to do this it would be necessary to place the apparatus in a room which is far away from all sources of disturbance, and which can be kept at a nearly constant temperature; and by decreasing the effect of the resistance of the air, thus enabling a larger number of swings to be observed. This last result may be accomplished either by increasing the moment of inertia of the suspended system, by swinging it in an atmosphere of hydrogen, or better still, in a vacuum. Professor Boys considers the last plan impracticable, but it seems to me that the vacuum might be maintained by making the outer case of the instrument as tight as possible and partially exhausting it also, thus reducing the difference in pressure on the two sides of the inner tube. There would also seem to be certain advantages in recording both the deflections and the periods photographically, and thus eliminating the personal errors in reading the elongations and transits.

F. L. O. W.

PROPOSED METHODS OF APPLYING THE OBJECT-GLASS PRISM TO THE MEASUREMENT OF STELLAR MOTIONS.

Méthode pour étudier les variations de vitesse radiale des astres avec de faibles instruments. H. Deslandres. *A.N.* 3328, **139**, 241–244, 1896. *A Method of Investigating the Velocity of Stars in the Line of Sight with Small Instruments.* H. Deslandres. *Observatory*, **19**, 49–52, 1896.

The Objective Prism and the Motions of Stars in the Line of Sight. E. W. Maunder. *Observatory*, **19**, 84–86, 1896.

Professor Orbinsky's paper[1] on the application of the object-glass prism to the determination of the motions of stars in the line of sight has led to a number of suggestions from other observers who are interested in the same subject. Briefly stated, the method of Orbinsky is to measure the contraction or dilation of the whole spectrum caused by the unequal displacement of different lines. The chief objections to the method are: (1) the differential displacement which is measured is, under the most favorable circumstances, hardly more than half the absolute displacement of the mean spectrum, and (2) in order to make this differential displacement as large as possible, widely separated lines must be used, and hence the exposure must be longer than that required for the most active part of the spectrum near the $H\gamma$ line.

In this method the spectra of the two stars whose velocities are compared are photographed side by side on the same plate, and no terrestrial spectrum is used.

The arrangement of apparatus proposed by M. Deslandres provides for a comparison spectrum, which is obtained as follows: A small totally-reflecting prism is cemented to the center of the outside face of the objective prism, and this prism receives the rays from a collimator, which is placed at right angles to the incident rays from the star, and reflects them through the main prism. In front of the collimator slit is placed the terrestrial source of light; thus the collimator, objective prism and main telescope form a slit spectroscope, the prism and camera of which are shared in common with the star spectroscope.

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[1] *A.N.* 3289, **138**, 9–12, 1895. Reviewed in this Journal, **2**, 235, 1895.

With this apparatus the star spectrum and the terrestrial spectrum are photographed simultaneously; at any subsequent time the same operation can be repeated for another star, the spectrum of which is photographed alongside of the first, and the relative velocities of the stars can then be determined by comparing the positions of corresponding lines. The difference of velocity of the two stars is given by the displacement between the stellar spectra minus that between the two terrestrial, the comparison spectra thus serving to eliminate errors due to flexure and changes of temperature.

Some of the special features of this method may now be considered. Since a displacement of the main telescope causes a shifting of the stellar spectrum on the plate, but does not affect the position of the comparison spectrum, it follows that the telescope must have precisely the same direction relatively to each of the stars observed. This condition is met by attaching to the main telescope a finder, or guiding telescope provided with cross-wires, which is directed to the star itself and is therefore inclined at a considerable angle to the main tube. Further, errors in guiding during the exposure affect the relative position of the spectra, and to determine these errors M. Deslandres proposes to attach a third, photographic telescope to the finder, so that the star can be photographed during the exposure, and its place determined with reference to the illuminated lines of a reticle placed close in front of the plate.

We have, therefore, in this apparatus, a photographic telescope with object-glass prism, a collimater projecting at a large angle from its upper end and furnished with suitable means for producing comparison spectra, a guiding telescope inclined at a large angle to the first, and a photographic telescope with illuminated reticle; and all these parts must be rigidly connected to prevent relative flexure. It is evident that this is by no means a simple and inexpensive piece of apparatus, even with the ingenious modifications which M. Deslandres has also suggested.

But the proposed method has a theoretical defect which seems likely to be fatal. The refracting angle of an object-glass prism is usually small, and hence the small central area set aside for the slit spectroscope would have a very low resolving power. If we suppose the refracting angle to be 45°, an area 3^{cm} square would have a resolving power of about 2300, which is not much more than sufficient to clearly separate the D lines. In any case there would be a great disparity in the resolving power of the two spectroscopes, and we should have sharp star spectra and badly defined comparison lines.

Mr. Maunder recalls a number of plans for using the object-glass prism, which occurred to him when spectroscopic work was first begun at Greenwich, and also later when photographic methods were brought into use. His first idea is essentially that of Orbinsky, but he was satisfied that the measurements required were too delicate for visual methods. A later plan was to measure the total deviation of a ray by the prism, by photographing the spectrum and then the star itself on the same plate, measuring the angle between the two directions of the telescope by means of an accurately divided declination circle. Still another method which could be employed when the prism did not cover the whole object-glass, was to compare the position of a line in the spectrum with a star image formed by rays from the outer parts of the objective. The declination of the star being known from the catalogue, the deviation of the line could be computed, but the corrections for refraction would be troublesome. All these methods seemed to Mr. Maunder at that time to be lacking in the necessary precision, and no attempt was made to carry them out practically.

J. E. K.

RECENT PUBLICATIONS.

A LIST of the titles of recent publications on astrophysical and allied subjects will be printed in each number of THE ASTROPHYSICAL JOURNAL. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors.

For convenience of reference, the titles are classified in thirteen sections.

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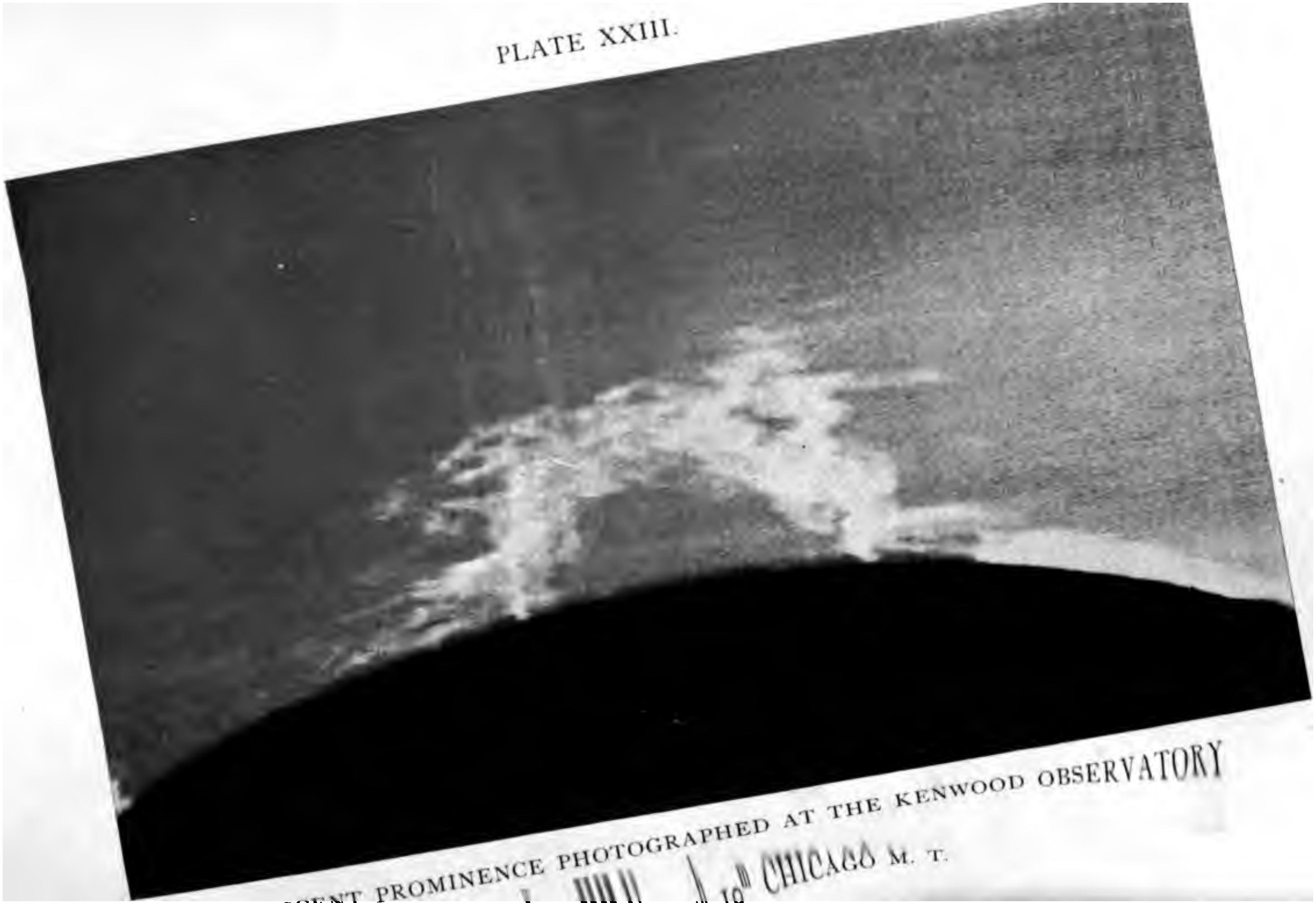
PLATE XXIII.



QUIESCENT PROMINENCE PHOTOGRAPHED AT THE KENWOOD OBSERVATORY
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THE
ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOLUME III MAY 1896 NUMBER 5

THE MODERN SPECTROSCOPE. XVIII.

ON THE CONDITIONS OF MAXIMUM EFFICIENCY IN THE USE OF THE SPECTROGRAPH.

By F. L. O. WADSWORTH.

IN the last paper of the Modern Spectroscope series I briefly indicated the conditions which it was necessary to fulfill in order that the *photographic* resolution of a given optical instrument should be equal to the *theoretical* visual resolution. In this case, which was the only one considered, we have to deal with the resolution of very fine lines or points whose angular width, as viewed from the camera, is negligible in comparison with the angle subtended by a wave-length of light at a distance equal to the diameter of the object-glass, such, for example, as stars, fine details on the lunar or the solar surface, and in the case of the spectrograph, the spectral images of *very* narrow slits. In this paper I propose to consider the whole question of photographic resolution more in detail and to point out that in spectrographic work, with slits of the width that are practically used, the conditions of efficiency are very different in the case of stars and other sources of very small angular magnitude, from the case of extended sources such as the Sun, the nebulæ, and the planets.

Although the conditions of efficiency in the case of the spectroscope have been discussed by a number of writers, and are now generally (though unfortunately not universally) recognized in spectroscopic work, no one has, as far as I have been able to find, considered this general question in the case of the spectrograph, save from the standpoint of practical experiment. Indeed, Mr. Newall, in discussing this question in his recent interesting paper on the new Bruce spectrograph of the Cambridge Observatory,[1] says: "The only considerations which bear on this point (relation of focal length of camera to resolving power of instrument) are practical." I do not agree with Mr. Newall in this statement, for, as I hope to show, there are certain theoretical considerations which are at least useful in indicating the limits, so to speak, of the design, not only as regards this particular point, which is perhaps one of those of the greatest importance, but as regards others of almost equal weight.

In considering the general conditions of efficiency in the case of the *astronomical spectroscope*,[2] the condition which I assumed as a basis of comparison was that of a constant visual resolving power r. In the case of the *spectrograph* we shall correspondingly assume a constant photographic resolution, a quantity which we will designate as q, and which will depend on the visual resolution r, on the angular aperture of the camera objective β, and on the structure or grain of the photographic plate. Let us first eliminate the question of the spectroscope train entirely, and consider only the resolution of the camera lens. The function of this is to form diffraction images of a series of points or lines, and it is evident that only those will be "resolved" (either visually or photographically) whose angular separation exceeds a certain limiting value depending on the width of the diffraction pattern, *i. e.*, both on the diameter of the objective and on the angular width of the lines or points themselves. Let us call this limiting value α in the case of visual observations and α_q in the case of photographic records. Then, as we have already shown in the preceding paper, we have for the case of *narrow* lines or points

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[1] *Ap. J.*, 3, 276, April 1896.

[2] *Ap. J.*, 1, 52–79, January 1895.

$$\alpha_0 = m\frac{\lambda}{a'} \qquad (1)$$

$$\alpha_q = \frac{ne}{f'} = \frac{ne\beta}{a'} \qquad (2)$$

where a' and f' and β are respectively the linear aperture, focal length and angular aperture of the lens, m is a constant varying from unity for a rectangular aperture to about 1.1 for a circular aperture (Rayleigh, Wave Theory, *Enc. Brit.*, **24**, 434), n, a whole number (taken as 4 in the preceding paper), and e the mean diameter of the silver grains.

Next let us consider the case of lines having a width s, and of uniform brightness across their whole width. Under these conditions it has been generally assumed that for distinct resolution the angular distance between the contiguous edges of the two lines must be equal to the resolving power of the aperture through which they are viewed. According to this assumption the angular distance between the centers of the two lines of width s, which would be just resolved, would have to be

$$\frac{1}{f'}\left(s\frac{f'}{f} + m\frac{\lambda}{a'}f'\right) = \left(\frac{s}{f} + m\frac{\lambda}{a'}\right) = \frac{1}{a'}\left(s\psi + m\lambda\right), \qquad (3)$$

where ψ is the angular magnitude of the aperture a', as viewed from the line s, and f is the distance of the line itself from the lens. This is the assumption on which the ordinary formula for the purity of a spectrum is based. But I have recently found that it may be shown, both by theory and by experiment, that this assumption is incorrect, and that the resolving power of an instrument for wide lines is considerably greater than is indicated by the above expression. As this point has apparently escaped notice heretofore it may be considered a little in detail.

The diffraction pattern due to a line of width s, or angular width $\sigma = \frac{s}{f}$, is found by integrating the effect due to each linear element over the whole width of the line. In the case of a rectangular aperture the diffraction pattern due to each linear element is represented by the dotted curves of Fig. 7 (*Ap. J.*, March 1896, p. 188), whose equation, as is well known, is

$$I = C\frac{\sin^2\frac{\pi}{\alpha}\phi}{\left(\frac{\pi}{\alpha}\phi\right)^2},$$

ϕ being the angular distance from the center of the diffraction image. The intensity at any point γ due to the effect of all of the elements of a line of uniform brightness, will therefore be

$$I' = C\int_{\frac{\sigma}{2}}^{\frac{\sigma}{2}} \frac{\sin^2\frac{\pi}{\alpha}(\gamma-\phi)}{\left[\frac{\pi}{\alpha}(\gamma-\phi)\right]^2}d\phi$$

$$= C'\int_{\frac{\pi}{\alpha}\left(\gamma-\frac{\sigma}{2}\right)}^{\frac{\pi}{\alpha}\left(\gamma+\frac{\sigma}{2}\right)} \frac{\sin^2 x}{x^2}dx = f(\gamma, \sigma) \qquad (4)$$

The value of the definite integral in (4) cannot be found directly in terms of γ and σ, but it can easily be evaluated by mechanical quadrature for different values of these variables. It was so evaluated for values of σ, varying from $\sigma=0$ to $\sigma=3\alpha$. The diffraction patterns for three sources of width $\sigma=\alpha$, $0=2\alpha$ and $\sigma=3\alpha$ respectively are shown in dotted lines in Plate XXIV., Fig. 1.

In order that a double line may be resolved it is necessary that the intensity at the center of the diffraction pattern of the double source (shown in full lines in Fig. 1), should be about 0.8, the intensity at the maxima corresponding to the centers of the two geometrical images. In order that this may be the case the distance between these centers in the three cases illustrated in the figure must be

for $\sigma=\alpha$ angular distance between centers $= 1.27\,\alpha = \sigma + .27\,\alpha$
$\sigma = 2\,\alpha$ " " " " $= 2.21\,\alpha = \sigma + .21\,\alpha$
$\sigma = 3\,\alpha$ " " " " $= 3.20\,\alpha = \sigma + .20\,\alpha$
or in general, " " " " $= \Sigma = \sigma + \delta$

From these and intermediate values the curve in Fig. 2, which represents the relation between the angular width of the

PLATE XXIV.

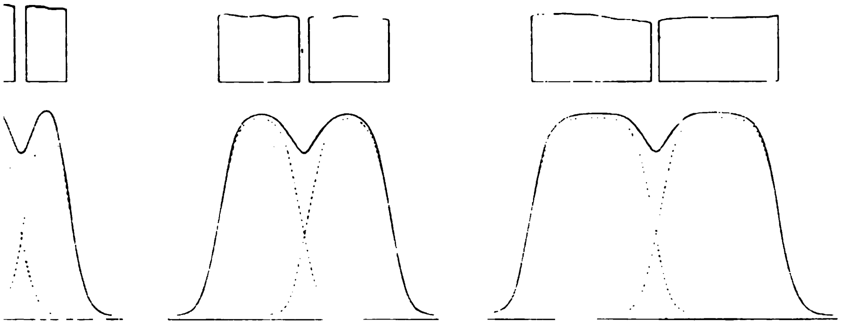


Fig. 1.

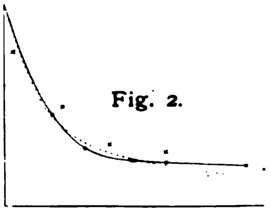


Fig. 2.

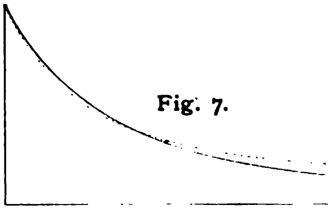
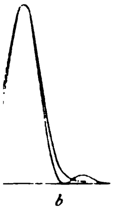


Fig. 7.



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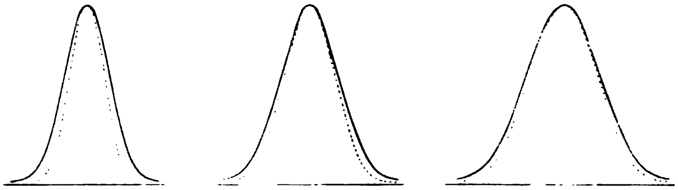

Fig. 4.

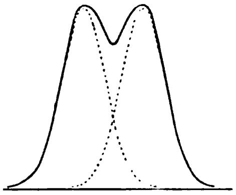

Fig. 5.

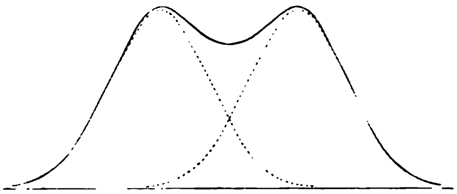

Fig. 6.

lines and the angular distance δ between the contiguous edges necessary for distinct resolution, was plotted.

In order to test these results experimentally a fine black wire was stretched across the center of an ordinary double motion slit, thus forming two parallel slits whose widths could be simultaneously varied (by opening the slit), while the distance between the contiguous edges (which was equal to the diameter of the wire) remained constant. The two slits were uniformly illuminated by the light of an electric arc passing through a screen of white paper; and viewed by a telescope over whose objective was placed a rectangular opening whose width, at right angles to the length of the two slits, could be varied.

The slits were set at various measured widths and the aperture in front of the telescope varied until the two slits were just "resolved." The aperture necessary for resolution when the slits were infinitely narrow, would evidently be:

$$A = \frac{\lambda}{\alpha},$$

where α is the angular diameter of the wire as seen in the telescope. For slits of finite width σ, the aperture a' required for resolution was less, and the ratio $\frac{A}{a'}$ measures the ratio of the resolving power of the full aperture A to the angular separation of the two edges necessary to obtain resolution with the same aperture, when the lines have a width σ. In the case of these experiments, the angular width of the wire was about 0.000018 or not quite 4″. Hence A was about 33^{mm}.

The results are presented in the following table:

TABLE I.

σ	a'	$\frac{\sigma}{\alpha}$	$\frac{a'}{A} = \frac{\delta}{\alpha}$
0″.36 (?)	25^{mm}–28^{mm}	0.10 (?)	0.75–0.82
2 .7	17^{mm}	0.75	0.51
4 .7	11	1.30	0.33
7 .2	9	2.00	0.27
11 .7	6	3.25	0.18
16 .2	5	4.5	0.15

For comparison with theory the first five results are plotted in Fig. 2. The agreement with the theoretical curve is as good as could have been expected under the conditions of observation. There was a great deal of vibration of the building at the time, and the light was also unsatisfactory; both of these causes tended to confuse the two images, and therefore to prevent distinct resolution with as narrow an aperture as might otherwise have been used.

The curve of Fig. 2 may up to the point $\sigma = 3\alpha$ be closely represented by the hyperbola of the form, (see dotted curve),

$$\frac{\sigma}{\alpha} + \tfrac{1}{2} = \frac{1}{2\left(\frac{\delta}{\alpha}\right)},$$

whence we get:

$$\delta = \frac{\alpha^2}{2\sigma + \alpha}.$$

But $\sigma = \frac{s}{f}$ and $\alpha = \frac{\lambda}{a'}$ (for rectangular aperture $m = 1$). Substituting these values we have:

$$\delta = \frac{1}{a'}\,\frac{\lambda^2}{2s\psi + \lambda}. \tag{5}$$

The angular distance between two lines of width σ which can just be resolved is then:

$$\Sigma = \sigma + \delta = \frac{1}{a'}\left(s\psi + \frac{\lambda}{2s\psi + \lambda}\lambda\right), \tag{6}$$

instead of $\frac{1}{a'}(s\psi + \lambda)$, as ordinarily given. The difference between this last expression and (6) will amount, in the case of small values of $s\psi$, to over 50 per cent. This point will be considered more in detail in the application of these results to the theory of the spectroscope.

Photographically, only those lines will be resolved for which the distance $\sigma + \delta$ is equal to or exceeds $\frac{ne}{f}$ or $\frac{ne\beta}{a'}$. Hence, if we call Σ_γ the photographic resolution for wide lines, we will have:

for

$$\left.\begin{aligned} &\left(s\psi+\frac{\lambda}{2s\psi+\lambda}\lambda\right)\geqq ne\beta \\ &\Sigma=\Sigma_q\,; \end{aligned}\right\} \quad (7)$$

or, to put it in another way, when the focal length of the camera is such that the quotient of n times the diameter of the silver grain by the focal length is equal to or less than the angular separation necessary for visual resolution, all of those lines which can be visually resolved, will also be photographically resolved. But when

$$\left.\begin{aligned} &\left(s\psi+\frac{\lambda}{2s\psi+\lambda}\lambda\right)< ne\beta, \\ &\text{then} \\ &\frac{\Sigma_q}{\Sigma}=\frac{ne\beta}{s\psi+\dfrac{\lambda}{2s\psi+\lambda}\lambda} \\ &\text{or} \\ &\Sigma_q=\frac{ne\beta}{s\psi+\dfrac{\lambda}{2s\psi+\lambda}\lambda}\quad \Sigma=\frac{ne\beta}{a'} \end{aligned}\right\} \quad (8)$$

as before.

As the width of the lines s becomes greater, the photographic resolution of the camera objective becomes more and more nearly equal to the visual resolution for all focal lengths. In order that the photographic resolution shall be equal to the visual for fine lines, we must have from (1) and (2)

$$\beta=\frac{\lambda}{ne}. \quad (9)$$

In the preceding paper it was shown that n should be at least 4, in order to ensure photographic resolution under all conditions. Under favorable conditions we might have distinct resolution if n were 3, but there could hardly be definite and assured separation of the photographic images if the number were less than this.

Hence, for the limiting values of β we have

$$\frac{\lambda}{4e}<\beta<\frac{\lambda}{3e},$$

or the angular aperture of the camera objective ought not to be greater than one-third the ratio between the wave-length of light and the diameter of the silver grain. If we assume for ϵ the value found by Holden for the plates used for lunar photography at Lick Observatory,[1] we find for β:

For $\lambda = 5893$ and $n = 3$. $\beta = 0.039$, or the focal length should be about 26 times the aperture.

For $\lambda = 3970$ (H) (which is near the maximum of photographic action), and $n = 3$. $\beta = 0.026$, or the focal length should be about 40 times the aperture.

In an ordinary rapid dry plate, the diameter of the grains is considerably larger than that given above; on the most rapid plates from two to three times as large. Mr. Newall's measurements give, for the *distance between centers* of the reduced grains, results varying from $0^{\mathrm{mm}}.01$ to $0^{\mathrm{mm}}.035$ or on the average about $0^{\mathrm{mm}}.025$. But, as previously stated, I have found that in those portions of the negative which are of average density the reduced silver grains are separated by about their own diameter, only every alternate grain being on the average affected. The *diameter* of the grains on Mr. Newall's plates will, therefore, be, on this assumption, about that stated above, or from $0^{\mathrm{mm}}.01$ to .015.

For grains of this size the angular aperture of the camera objective requisite to give the maximum of photographic resolution, would, for the two cases considered above, be respectively:

For $\lambda = 5893$. $\beta = 0.019$ to 0.013, or the focal length should be from 50 to 75 times the aperture. For $\lambda = 3970$. $\beta = 0.013$ to 0.009; focal length from 75 to 110 times the aperture. For $n = 4$, all of these ratios of focal length to aperture are increased one-third.

Under the most favorable conditions, then, the focal length of the camera should not be less than about 40 times the aperture (since the maximum of photographic action on an ordinary plate lies near the H line), if the finest details of an object are to be photographically reproduced. It is interesting to note that this is very nearly the ratio adopted by Rowland for his concave gratings (43 to 1). Usually the resolution on the photographic plate is not quite equal to the visual resolution of this instrument under similar conditions of use. On the other hand, the above considerations show that there is no advantage in making the focal length greater than about 100 times the aperture, except under the most unfavorable conditions; and that, so far as photographic definition and resolution are concerned, it would be absurd to make it several hundred times the aperture, as has been sometimes proposed. Indeed the theoretical advantage gained in making it even 100 times the aperture may be more than compensated by the increased haziness resulting from the necessary increase in exposure time. In the case of the recent Lick Observatory photographs of the Moon (which were taken with the 36-inch stopped down to 8 inches), the ratio of focal length to aperture was about 75 to 1. With plates of the grain used by Professor Holden, this is about twice as large as would be necessary to photographically resolve all the details that could be resolved with this aperture. If, then, the focal length had been shortened by one-half just as good results ought to have been obtained; even better, for the exposure time would have been only one-fourth that required with the instrument as actually used. Lest I be misunderstood, let me say that although under *perfect* conditions, the same result would be reached by doubling the linear aperture (the focal length remaining constant), this would, by no means, be true under the practical conditions which exist in lunar and, in fact, celestial photography in general—since owing to a number of causes (of which the most important are the atmospheric disturbances), the use of large linear apertures has inherent difficulties of its own, which it will be extremely difficult, if not impossible, to ever overcome.

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[1] *Pub. of the Lick Observatory*, **3**, 12.

If our purpose is to photographically resolve only those details of an object, which have an angular separation Σ (say a series of uniform, bright lines having a width s), then we may with advantage increase the angular aperture of the camera until (see 7 and 8) we have

$$\beta = \frac{s\psi + \frac{\lambda}{2s\psi + \lambda}\lambda}{ne}, \qquad (10)$$

where, as before, n varies from 3 to 4.

Under these conditions, we would still photographically resolve all the details that could be visually resolved. Suppose for example, $s = 0^{mm}.01$ and $\psi = \frac{a'}{f} = \frac{1}{10}$, *i. e.*, the line is ten times the diameter of the objective from the latter. Then $s\psi = 0.001$ and

$$\left.\begin{array}{l} \beta = 0.076 \text{ or } \frac{f'}{a'} \backsimeq 13 \text{ for } \lambda = 5896 \\ \beta = 0.071 \text{ or } \frac{f'}{a'} \backsimeq 14 \text{ for } \lambda = 3970 \end{array}\right\} \begin{array}{l} n = 3 \\ e = .005 \end{array}$$

For $e = 0^{mm}.01$ to $0^{mm}.015$, the ratios of focal length to aperture will range from 27 to 43 for $n = 3$; and from 36 to 54 for $n = 4$.

This last case, that of photographic resolution of lines of finite width, is the one which we meet with in the spectrograph, in which the object photographed is the spectral image of the slit of width s. Here we are concerned not only with the photographic resolution but with the brightness of the spectrum, since upon this latter characteristic will depend the time of exposure, which is quite as important in determining the final goodness of the result as the photographic resolving power.

In order to determine the most advantageous aperture to employ in the various cases which may arise (stellar spectrography, solar spectrography and planetary and nebular spectrography), it is now necessary to consider the relation between the photographic resolution of the spectroscope train *as a whole* and the resulting brightness of spectrum. The spectroscope train may be looked upon simply as a means of producing a series of monochromatic (or nearly monochromatic) images of a single source, the slit of the spectroscope, and of these images, it is evident that only those will be "resolved", or separated, for which the difference in angular dispersion is equal to or greater than the corresponding angular resolution α or Σ of the camera objective. In the case of spectral images of a slit this width is a function of two quantities; (1) the width of the slit s, (2) the dispersion of the spectroscope train, which for radiations not monochromatic produces the same effect as a widening of the slit. Theoretically we should distinguish between four cases:

1. The resolving power (theoretical) of a spectroscope train for an infinitely narrow slit and monochromatic radiations, *i. e.*, infinitely narrow spectral lines. This is the quantity usually denoted by r (for visual resolution).

2. The resolving power (also theoretical) for a wide slit and monochromatic radiations. Usually denoted by p, the "purity" of the spectrum.

3. The resolving power (theoretical) for an infinitely narrow slit, but for lines of finite width $\Delta\lambda$. This quantity we will denote by R (visual resolution).

4. The resolving power (practical) for a wide slit and non-monochromatic radiations, ranging for each line over a small value $\Delta\lambda$ as in (3). The practical visual resolving power we will denote by P; and the corresponding photographic resolution by Q. They represent the practical visual and photographic purity of the spectrum.

Let $D = \frac{d\theta}{d\lambda}$ be the angular dispersion of the spectroscope train. The spectroscopic resolution for any case is defined by the ratio $\frac{\lambda}{d\lambda}$, where $d\lambda$ is the difference in wave-length of two lines of mean wave-length, λ, that are just resolved. Therefore for the first case

$$\frac{d\theta}{d\lambda}(d\lambda)_1 = \alpha = m\frac{\lambda}{a'}$$

$$\text{or } r = \frac{Da'}{m}; \qquad (11)$$

a perfectly general relation which holds good whatever may be the nature, form or arrangement of the spectroscope train.

For the second case

$$\frac{d\theta}{d\lambda}(d\lambda)_2 = \Sigma = \frac{1}{a'}\left(s\psi + \frac{\lambda}{2s\psi + \lambda}\lambda\right)$$

$$\text{or } \frac{\lambda}{(d\lambda)_2} = p = \frac{\lambda}{s\psi + \frac{\lambda}{2s\psi + \lambda}\lambda}r, \qquad (12)$$

which differs from the expression ordinarily given for the purity of a spectrum by the presence of the factor $\frac{\lambda}{2s\psi + \lambda}$ as a coefficient of the second term of the denominator. The existence of this factor necessitates a considerable modification of certain statements based on the old formula for purity. For example, Schuster in his remarks on the practical purity of a bright line spectrum in the article "Spectroscopy," (*Enc. Brit.* **22**, 374) says: "The maximum illumination for any line is obtained when the angular width of the slit is equal to the angle subtended by one wave-length at a distance equal to the collimator aperture. In that case $s\psi = \lambda$ and the purity is half the resolving power. Hence when light is a consideration we shall not as a rule realize more than half the resolving power of the spectroscope." Equation (12) shows however that under this condition for maximum illumination[1] the purity is really 75 per cent. of the theoretical resolving power instead of 50 per cent. as indicated by Schuster. A similar erroneous conclusion (based upon the commonly accepted formula for purity) was drawn by the writer in one of his earlier papers,[2] in which it was stated that the purity in the case of stellar spectra could never exceed one-third the theoretical resolving power (unless the slit width is made less than the diameter of the diffraction image of the star). Equation (12) shows us that this limit should be nearly one-half instead of one-third.

Third case. If the radiation is not monochromatic, but is made up of wave-lengths ranging over an interval from λ to $\lambda + \Delta\lambda$, the dispersion of the spectroscope train will spread out the image of an infinitely narrow slit into a band in which the distribution of intensity (supposing the dispersion over the small range $\Delta\lambda$ to be strictly proportional to λ) will be the same as in the source of radiation.

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[1] As I have previously shown this condition holds only for absolutely monochromatic sources of radiation. *Ap. J.*, January 1895, pp. 62, 63.

[2] *Ap. J.*, January 1895, pp. 68, 69.

This image will be further broadened by diffraction, and the distribution of intensity in the image formed by the camera objective will be given by an expression similar to (4), but containing a term $f(\phi)$, which represents the distribution of intensity in the source of radiation.

The law of distribution (in a normal source) is not yet definitely known. The one ordinarily assumed is that which follows from Maxwell's kinetic theory, which is[1]

$$f(\phi) = e^{-\kappa\phi^2} \qquad (13)$$

where κ is a constant whose value varies with the substance emitting radiation and with the temperature and pressure in the source. A law of distribution more recently proposed by Michelson, is[2]

$$f(\phi) = e\frac{\sin^2 r\phi}{\phi^2}. \qquad (14)$$

If the first law is assumed we, have for the intensity in the diffraction pattern

$$I_1 = \int_{-\infty}^{+\infty} e^{-\kappa\phi^2} \frac{\sin^2\frac{\pi}{a}(\gamma-\phi)}{\left[\frac{\pi}{a}(\gamma-\phi)\right]^2} d\phi = \psi_1(\kappa, \gamma, a,); \qquad (15)$$

and if the second

$$I_2 = \int_{-\infty}^{+\infty} \frac{\sin^2 r\phi \sin^2\frac{\pi}{a}(\gamma-\phi)}{\phi^2\left[\frac{\pi}{a}(\gamma-\phi)\right]^2} d\phi = \psi_2(r, \gamma, a). \qquad (16)$$

I have not succeeded in integrating either of these integrals in finite form. They may be integrated by developing into a series, but I have found it quicker and easier to integrate by mechanical quadrature. Owing to the very close correspondence between the curves represented by (13) and (14) (see Fig. 3), the result will be practically the same whichever law be adopted. The expression for I_1 (15), is one which has actually been integrated and the resulting curves $\psi_1\,(\kappa, \gamma, a)$ for three values of κ are given in Fig. 4. The dotted lines represent the curves $f\,(\phi)$ and the full lines the resulting diffraction pattern $\psi_1\,(\gamma)$.

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[1] See Rayleigh, *Phil. Mag.*, April 1889, p. 298, also Michelson, *Phil. Mag.*, September 1892.

[2] *Ap. J.*, November 1895, p. 251.

For convenience the values of κ are expressed in terms of δ, the "half width" of the line (Michelson) and a, the limiting resolving power of the camera objective. The "half width" δ is defined to be the value of ϕ for which $f\,(\phi) = \frac{1}{2}$. Hence

$$\kappa = \frac{\text{nap log } 2}{\delta^2}. \tag{17}$$

What we may call the effective width of the line w is the width *a b*, Fig. 3, which is equal to 4δ. At the points *a* and *b* the intensity $f\,(\phi)$ is only about one-twentieth the intensity at the center, and the part of the curve beyond this point may therefore be considered as having but little effect either on the eye or on the photographic plate.

The values of w in the curves of Fig. 4 are $w = a$, $w = 2a$, $w = 3a$.

In Fig. 5 the diffraction curve for a double source, of which each component is of width $w = a$, is shown. Adopting the same rule as before, *i. e.*, that for resolution the intensity at the middle of the diffraction pattern must not be more than 0.8 the intensity at the two maxima on each side, we find that for resolution the distance between the components in different cases must be

$$\begin{array}{lll}
w = a & \text{dist.} & = 1.12a = \Omega_1 \\
w = 2a & \text{"} & = 1.45a = \Omega_2 \\
w = 3a & \text{"} & = 1.90a = \Omega_3 \\
w = 4a & \text{"} & = 2.45a = \Omega_4
\end{array}$$

For lines so wide that the broadening by diffraction can be entirely neglected we find (Fig. 6) that the distance between the components necessary for resolution is

$$2.3\delta = .575\,w \backsimeq \tfrac{4}{7}\,w.$$

Expressing the preceding results in the form

$$\Omega = \tfrac{4}{7}\,w + f\,(w)\,a$$

we have

for $w = 0$	$f(w) = 1.00$	$\Omega = a = \frac{\lambda}{a'}$,
for $w = a$	$f(w) = 0.55$	$\Omega = \frac{4}{7} w + 0.53 \frac{\lambda}{a'}$,
for $w = 2a$	$f(w) = 0.31$	$\Omega = \frac{4}{7} w + 0.31 \frac{\lambda}{a'}$,
for $w = 3a$	$f(w) = 0.18$	$\Omega = \frac{4}{7} w + 0.20 \frac{\lambda}{a'}$,
for $w = 4a$	$f(w) = 0.15$	$\Omega = \frac{4}{7} w + 0.15 \frac{\lambda}{a'}$,
for $w = \infty a$	$f(w) = 0$	$\Omega = \frac{4}{7} w + 0.00 \frac{\lambda}{a'}$.

The coefficients $f(w)$ of the last term are plotted in Fig. 7 as a function of w. The first portion of this curve may, as in the case of Fig. 2, be closely represented by an empirical hyperbola (dotted curve), whose equation is

$$\frac{w}{a} + 1 = \frac{1}{f(w)} \text{ or } f(w) = \frac{a}{w + a},$$

whence

$$\Omega = \frac{4}{7} w + \frac{a^2}{w + a}.$$

The angular width of the line ω, since this is produced by the dispersion of the spectroscope train, is

$$\omega = D \Delta\lambda,$$

$$\therefore \ \Omega = \frac{1}{a'} \left(\frac{4}{7} r \Delta\lambda + \frac{\lambda}{r\Delta\lambda + \lambda} \lambda \right); \tag{18}$$

and therefore for the spectroscopic resolution

$$\frac{d\theta}{d\lambda} (d\lambda)_3 = \Omega,$$

and

$$R = \frac{\lambda}{(d\lambda)_3} = \frac{\lambda}{\frac{4}{7} r \Delta\lambda + \frac{\lambda}{r\Delta\lambda + \lambda} \lambda} r, \tag{19}$$

a formula very similar in form to that derived for the purity p in the case of a wide slit and monochromatic radiation.

Fourth case. In order to determine the limit of resolution or the practical purity P in this, the most important case, we must first determine the diffraction curve resulting from a superposition of all the elements of the slit. If as before these elements are equal in intensity, *i. e.*, if the illumination over the whole width of the slit is uniform, the intensity curve of the diffraction image will be

$$I_{\rm II} = \int_{-\frac{\sigma}{2}}^{+\frac{\sigma}{2}} \psi_{\rm I}(\xi - \gamma, w', a)\, d\xi = \psi_{\rm II}(\sigma, \gamma, w, a)\,, \tag{20}$$

where

$$\psi_{\rm I}(\gamma, w', a) = \int_{-\infty}^{+\infty} 2^{-\left(\frac{2\phi}{w'}\right)^2} \frac{\sin^2 \frac{\pi}{a}(\gamma - \phi)}{\left[\frac{\pi}{a}(\gamma - \phi)\right]^2}\, d\phi\,, \tag{15a}$$

as derived from (15) and (17).

Since the function $\psi_{\rm I}$ itself is not known in finite terms $\psi_{\rm II}$ can not be directly found. We may however approximate very closely indeed to it by replacing the function $\psi_{\rm I}$ by the function

$$\frac{\sin^2 \frac{\pi}{\Omega}\gamma}{\left(\frac{\pi}{\Omega}\gamma\right)^2}\,, \tag{21}$$

which up to the point $\gamma = \frac{\Omega}{2}$, or over all that part of the curve which is important in determining the limits of resolution of a double line, coincides almost exactly with the curve $\psi_{\rm I}(\kappa, \gamma, a)$.

The expression for $I_{\rm II}$ then becomes

$$I_{\rm II} \cong \int_{-\frac{\sigma}{2}}^{\frac{\sigma}{2}} \frac{\sin^2 \frac{\pi}{\Omega}(\xi - \gamma)}{\left[\frac{\pi}{\Omega}(\xi - \gamma)\right]^2}\, d\xi\,, \tag{22}$$

which is exactly similar in form to (4), the only difference being that a has been replaced by Ω.

We may therefore obtain at once the limit of resolution for this case from (6) by replacing a by Ω, giving us

$$\text{limiting angular resolution} = \sigma + \frac{\Omega^2}{2\sigma + \Omega}\,.$$

Replacing σ and Ω by their values in terms of s, ψ, R, r and λ and reducing we finally obtain as the limiting angular resolution, which we will call as before Σ,

$$\Sigma = \frac{1}{a'}\left[s\psi + \frac{\left(\lambda\frac{r}{R}\right)^2}{2s\psi + \lambda\left(\frac{r}{R}\right)}\right] \tag{23}$$

and for purity

$$P = \frac{\lambda}{(d\lambda)_4} = \frac{\lambda}{s\psi + \frac{\lambda\left(\frac{r}{R}\right)}{2s\psi + \lambda\left(\frac{r}{R}\right)}\left(\frac{r}{R}\right)\lambda}\, r. \tag{24}$$

This expression differs from (12) only in the presence of the factor $\frac{r}{R}$ as a coefficient of λ in the denominator.

The value of this ratio is greater (and P therefore smaller) as the width $\Delta\lambda$ of the line increases.

For a width $\Delta\lambda = 0.2$ tenth-meters (about the width of some of the lines of the solar prominences), and a resolving power of 25,000 units (a very common power)

$$r\Delta\lambda = 0.0005 \cong \lambda$$

and
$$\frac{r}{R} \cong \frac{4}{7} + \frac{1}{2} = 1.07.$$

In such cases, where the total width of the spectral image of the line is not greater than the half width of the diffraction image, the term $\frac{r}{R}$ may be taken to be equal to unity without sensible error. But in many cases the width of the line is much greater than this. For a resolving power of 150,000, for example, (such as is frequently employed in solar work), $r\Delta\lambda \cong 6\lambda$ and

$$\frac{r}{R} = \frac{24}{7} + \frac{1}{7} = 3.57.$$

Under these conditions for a width of slit s, such that $s\psi = \lambda$, we have for P

$$\frac{P}{r} = 0.3 \text{ and } \frac{P}{p} = 0.4,$$

or the practical purity is less than one-third the theoretical resolving power for monochromatic radiations and only two-fifths the theoretical purity for such radiations with the same width of slit. By increasing the resolving power of the instrument six times we have only increased the practical purity of the spectrum about two and one-half times. According to the commonly accepted formula for purity this ought to have increased in the same ratio as the resolving power. Conclusions in regard to the purity of the spectrum which have been based upon the old formula are consequently greatly in error for high resolving powers (over 100 per cent. in the case just cited).

For photographic purity we have:

$$\left.\begin{array}{ll}\text{when} & s\psi + \dfrac{\lambda^2 \left(\dfrac{r}{R}\right)^2}{2s\psi + \lambda\dfrac{r}{R}} \overset{=}{>} ne\beta \\[2em] \text{then} & Q = P\end{array}\right\} \qquad (25)$$

$$\left.\begin{array}{ll}\text{and when} & s\psi + \dfrac{\lambda^2 \left(\dfrac{r}{R}\right)^2}{2s\psi + \dfrac{\lambda r}{R}} < ne\beta, \\[2em] \text{then} & Q = \dfrac{s\psi + \dfrac{\lambda^2 \left(\dfrac{r}{R}\right)^2}{2s\psi + \lambda\left(\dfrac{r}{R}\right)}}{ne\beta} P = \dfrac{\lambda}{ne\beta} r.\end{array}\right\} \qquad (26)$$

For the brightness of the spectra we have:[1]

(1) For stellar spectra. (Suppose the slit to be at least as wide as the diameter of the first diffraction ring, under which conditions the usual purity of the spectrum is constant and equal to between one-half and one-third (according to the resolving power of the instrument) the visual resolving power of the spectroscope train).

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[1] *Ap. J.* January 1895, pp. 68, 69, 72.

a) Continuous spectra

$$i = \tfrac{1}{8} k \epsilon \beta^2 A^2 \frac{1}{r\lambda(\lambda_1 - \lambda_2)}. \tag{27}$$

b) Discontinuous (bright line) spectra

$$i = \tfrac{1}{4} k \epsilon \beta^2 A^2 \frac{1}{\lambda(2\lambda + \frac{1}{8} r \Delta\lambda)}. \tag{28}$$

(2) For spectra from continuous sources (or sources the angular magnitude of whose image is greater than $\frac{s}{f}$), supposing purity constant as before,

a) Continuous spectra

$$i = k \epsilon \beta^2 \frac{s}{r(\lambda_1 - \lambda_2)}. \tag{29}$$

b) Discontinuous spectra

$$i = k \epsilon \beta^2 \frac{1}{1 + \frac{2\lambda + r\Delta\lambda}{s}} \cong k \epsilon \beta^2. \tag{30}$$

First case. From an inspection of (28) and (30) we see at once that in the case of bright line spectra there is only one possible way of increasing the brightness *i. e.*, by increasing the angular aperture β of the camera. The photographic purity will be independent of the angular aperture up to the limit imposed by 25) but beyond that we must, in order to maintain the photographic purity constant, increase r in the same ratio as β or make

$$r = \frac{\beta}{\beta_0} r_0, \tag{31}$$

where r_0 is the initial theoretical resolution of the spectroscope train and β_0 is defined by the relation

$$\beta_0 = \frac{s\psi + \dfrac{\lambda^2 \left(\frac{r_0}{R_0}\right)^2}{2s\psi + \lambda\left(\frac{r_0}{R_0}\right)}}{ne}. \tag{32}$$

Up to the point $\beta = \beta_0$ the brightness of the spectrum increases in the ratio of β^2; beyond this point it still increases, but less rapidly, because of the increase in r necessary to preserve the photographic purity constant. This increase in r diminishes the intensity i by reason of an increase in the factor ϵ as well as by reason of the increase in r directly. From (28) we have

$$\frac{i}{i_0} = \frac{\epsilon \beta^2}{\epsilon_0 \beta_0^2} \cdot \frac{6\lambda + r_0 \Delta\lambda}{6\lambda + r\Delta\lambda}, \tag{33}$$

and from (30)

$$\frac{i}{i_0} = \frac{\epsilon \beta^2}{\epsilon_0 \beta_0^2} \cdot \frac{s + 2\lambda + r_0 \Delta\lambda}{s + 2\lambda + r\Delta\lambda}. \tag{34}$$

In both (33) and (34) the terms $r\Delta\lambda$ are, for the usual values of r and $\Delta\lambda$, small in comparison with the terms with which they are associated. Hence in comparing the intensities i and i_0, except for very large values of r_0, we may safely neglect these terms and write

$$\frac{i}{i_0} = \frac{\epsilon}{\epsilon_0}\left(\frac{\beta}{\beta_0}\right)^2. \tag{35}$$

The variation of ϵ, (which is a factor representing the losses by reflection, absorption and diffusion, in the spectroscope train), will vary greatly with the nature of the spectroscope, (grating or prismatic), and with the portion of the spectrum under examination (on account of the varying amount of absorption, diffusion etc., for radiations of different wave-length). Suppose we assume, for the purpose of comparison, that the value of ϵ will vary according to the following law:

for $r = r_0$ $\epsilon =$ .85 (1 prism or 1st order of grating)
for $r = 2r_0$ $\epsilon =$ .72 (2 prisms or 2d order of grating)
for $r = 3r_0$ $\epsilon =$ .60 (3 prisms or 3d order of grating)
for $r = 4r_0$ $\epsilon =$ .50 (4 prisms or 4th order of grating)
for $r = 5r_0$ $\epsilon =$ .45 (5 prisms or 5th order of grating)

which represents approximately the percentage amount of sodium light transmitted through 1, 2, 3, 4, 5 ordinary flint glass prisms. In the case of the grating the variation might be greater or less or even reversed on account of the anomalies of the grating.

Assuming the above law of variation for ϵ and assuming further that $\psi = \frac{1}{10}$ and $r_0 = 25000$ (very common values for ordinary spectrographs), the values of r and $\frac{i}{i_0}$ have been calculated for values of β ranging from one-fiftieth to one-fifth for three different widths of slit; *i.e.* $= s = 0^{mm}.01$, $0^{mm}.02$ and $0^{mm}.03$.

In this calculation the ratio $\frac{r}{R}$ has been taken as 1.1 (which makes $\Delta\lambda$ about 0.2 tenth meter); ne as $0^{\mathrm{mm}}.04$ ($e = 0^{\mathrm{mm}}.01$ and $n = 4$); and λ as $0^{\mathrm{mm}}.0004$ (about the position of maximum photographic action).

TABLE II.

$r_0 = 25{,}000$. Constant Photographic Purity $= Q_0$

β	$s = 0^{\mathrm{mm}}.01$ $\beta_0 = \frac{1}{37.4}$ $Q = 9350$			$s = 0^{\mathrm{mm}}.02$ $\beta_0 = \frac{1}{19.6}$ $Q_0 = 4900$			$s = 0^{\mathrm{mm}}.03$ $\beta_0 = \frac{1}{13.2}$ $Q_0 = 3300$		
	r	$\frac{e}{e_0}$	$\frac{i}{i_0} \times \left(\frac{\beta_0}{0.02}\right)^{2*}$	r	$\frac{e}{e_0}$	$\frac{i}{i_0} \times \left(\frac{\beta_0}{0.02}\right)^{2*}$	r	$\frac{e}{e_0}$	$\frac{i}{i_0} \times \left(\frac{\beta}{0.02}\right)^{2*}$
$\frac{1}{50} = 0.02$	25000	1.00	1.00	25000	1.00	1.00	25000	1.00	1.00
$\frac{1}{40}$	25000	1.00	1.56	25000	1.00	1.56	25000	1.00	1.56
$\frac{1}{30}$	31250	.96	2.67	25000	1.00	2.78	25000	1.00	2.78
$\frac{1}{20}$	46750	.87	5.44	25000	1.00	6.25	25000	1.00	6.25
$\frac{1}{10}$	93500	.63(?)	15.75(?)	49000	.84	21.00	33000	.96	24.00
$\frac{1}{5}$	187000	.30(?)	30.00(?)	98000	.59(?)	59.00(?)	66000	.76	76.00

[* The factor $\left(\frac{\beta_0}{0.02}\right)^2$ is introduced in order to make the ratio $\frac{i}{i_0} = 1$ for $\beta = \frac{1}{50}$.]

Let us consider one of the practical cases cited by Mr. Newall, *i.e.*, that of photographing the bright lines of α Orionis. With a slit width of $0^{\mathrm{mm}}.02$ and the telephoto lens of the Cambridge spectrograph (equivalent focal length of 20 times the aperture), 40 minutes exposure was required. If the angular aperture had been increased to one-tenth, and the resolving power r increased in the ratio $\frac{49000}{25000}$, or about two to one, the same degree of photographic purity would have been secured, and the time of exposure diminished in the ratio $\frac{i_0}{i} = \frac{21}{6.25}$, or over three and one-third times. The advantage of the short focal lengths in such a case as this are very evident. With a still wider slit the advantage would be even more marked, with a narrower one somewhat less. In the case of very narrow slits the increase in brightness is less than is indicated in the table, because of the neglect of the term $r\Delta\lambda$ in the denominator of equations (33) and (34). In the case of the largest value of r, ($r = 187{,}000$ or about $7r_0$), the calculated brightness is reduced about 20 per cent. in the case of spectra from extended sources, (34), and nearly 50 per cent. in the case of stellar spectra, (33), by taking account of this term. In the case of a slit width of $0^{mm}.01$ or less, it would not therefore be advantageous to increase the angular aperture β beyond one-tenth at the most.

Second case. Continuous spectra from extended sources. From (29) we see that in this case the intensity varies directly as β^2 and inversely as r. For two values of β we have from (29)

$$\frac{i}{i_0} = \frac{\epsilon}{\epsilon_0} \frac{\beta^2}{\beta_0^2} \frac{r_0}{r}.$$

Up to the point $\beta = \beta_0$, as defined by (25) or (32), the photographic purity remains constant for a given value of $r = r_0$ and the intensity therefore increases directly as β^2. But beyond this point we must, in order to maintain photographic purity constant, increase the resolving power in the ratio $\frac{\beta}{\beta_0}$. Hence for values of $\beta > \beta_0$ we have

$$\frac{i}{i_0} = \frac{\epsilon}{\epsilon_0} \frac{\beta}{\beta_0}. \qquad (36)$$

The values of $\frac{i}{i_0}$ are therefore the same as given in Table II. for values of β less than β_0. For values of β greater than β_0 they can be found by multiplying the corresponding values in that table by $\frac{\beta_0}{\beta} = \frac{r_0}{r}$. Their values so obtained are given in Table III. The values of β_0, $\frac{\epsilon}{\epsilon_0}$, r_0 and r are the same as before and therefore are not retabulated.

TABLE III.

β	$s = 0^{mm}.01$ $\beta_0 = \frac{1}{31.4}$ $\frac{i}{i_0} \times \left(\frac{\beta_0}{0.02}\right)^2$	$s = 0^{mm}.02$ $\beta_0 = \frac{1}{16.8}$ $\frac{i}{i_0} \times \left(\frac{\beta_0}{0.02}\right)^2$	$s = 0^{mm}.03$ $\beta_0 = \frac{1}{13.7}$ $\frac{i}{i_0} \times \left(\frac{\beta_0}{0.02}\right)^2$
$\frac{1}{50} = 0.02$	1.00	1.00	1.00
$\frac{1}{40}$	1.56	1.56	1.56
$\frac{1}{30}$	2.14	2.78	2.78
$\frac{1}{20}$	2.91	6.25	6.25
$\frac{1}{10}$	4.21	10.72	18.18
$\frac{1}{5}$	4.01	15.05	28.79

From an inspection of these values we see that the advantage of increasing the angular aperture beyond the value β_0 is a good deal less than in the preceding case. Still, in the case of an average slit width $s = 0^{mm}.02$, there is a very considerable gain in making it as large as $\frac{1}{10}$, and if sufficient resolving power is available even as large as $\frac{1}{8}$. Let us again consider a practical case given by Mr. Newall. For a slit width of $0^{mm}.02$ and the telephoto lens, ($\beta = \frac{1}{20}$), 7 minutes exposure was required to photograph the spectrum of Venus with the Bruce spectograph. If the angular aperture had been doubled ($\beta = \frac{1}{10}$) the resolving power would have had to be increased in the ratio $\frac{49}{25}$, in order to obtain the same photographic purity, but the intensity would have been increased in the ratio $\frac{10.72}{6.25}$ or nearly one and three quarter times. The necessary time of exposure then would have been only about 4 minutes. If the aperture had been made still larger, ($\frac{1}{8}$), the intensity would have been increased in the ratio $\frac{6.25}{15.05}$ or about two and one-half times, reducing the time of exposure to about 2¾ minutes, but the resolving power r would have had to be increased nearly four times. On the whole therefore it would not be an advantage to make the angular aperture larger than about one-tenth for this width of slit. For wider slits ($s = 0^{mm}.03$) the advantage of the larger angular apertures is greater, but for narrower ones very much less. In the case of slit widths of less than $0^{mm}.01$ (or of very small values of ψ) it may be even a disadvantage to make the angular aperture β any larger than the limiting aperture β_0. Let us consider the case of the concave grating, in which the conditions are somewhat different from those assumed in the calculation of the values in Table II. For the usual form of six-inch concave grating $\psi \backsimeq \frac{1}{40}$ and $r_0 \backsimeq 100000$.

For the same values of $\Delta\lambda$ and λ as assumed before we therefore have from (19)

$$\frac{r}{R} = \frac{87}{35} = 2.5,$$

and for a slit width of $0^{mm}.02$ (about the usual width)

$$\beta_0 = \frac{.0005 + .0005}{.04} = \frac{1}{40}, \qquad \text{from (32)}$$

or about the angular aperture which is actually used in these instruments. We can readily see that in this case there is no gain in making β larger than β_0. because the slight resulting gain in intensity is obtained only at a large increase in resolving power.

(3) *Continuous stellar spectra.* We have last to consider the important case of continuous stellar spectra. In this case the ratio of intensities for two apertures β and β_0 is (from 27)

$$\frac{i}{i_0} = \frac{\epsilon}{\epsilon_0}\left(\frac{\beta}{\beta_0}\right)^2 \frac{r_0}{r},$$

and for constant photographic purity

$$\frac{i}{i_0} = \frac{\epsilon}{\epsilon^0}\left(\frac{\beta}{\beta_0}\right), \qquad (37)$$

where β_0 is defined by (32), as in the preceding case. But what we are directly concerned with in the spectrograph is not the intensity of the spectrum, but the necessary time of exposure. In all of the preceding cases these two qualities have been inversely proportional, but they are not so in the case of stellar spectra. For on account of the insensible width of the spectrum even with the longest focal lengths of the camera objective, it is always necessary to allow the star to drift a certain amount on the slit plate in order to produce a spectrum wide enough for convenient examination and measurement. With a long focus camera the drift necessary to produce a given broadening would be less than with a short focus one, and if the amount of drift is regulated so that in each case the final breadth is the same, then the time of exposure will vary not as $\frac{i_0}{i}$, but as

$$\frac{i_0}{i} \times \frac{\beta}{\beta_0},$$

or

$$\frac{T_0}{T} = \frac{i}{i_0} \times \frac{\beta_0}{\beta} = \frac{\epsilon}{\epsilon_0}. \qquad (38)$$

So that in this case there is an actual increase in the time of exposure required when the angular aperture is made less than β_0, as defined by (32).

The limiting values of $\beta = \beta_0$ for slit widths of $0^{\mathrm{mm}}.01$, $0^{\mathrm{mm}}.02$, and $0^{\mathrm{mm}}.03$ have already been calculated on the assumption that e, the diameter of the silver grains, is $0^{\mathrm{mm}}.01$. But in stellar spectrographic work the extreme faintness of the spectrum makes it necessary to employ, at least for the fainter stars, the most rapid plates obtainable. For with a given degree of photographic purity and a given resolution, the focal length of the camera will increase directly with the diameter of the silver grain e and the intensity will therefore diminish as e^2. But the sensitiveness of the plate increases more rapidly (in general) than the square of the diameter of the grain, and it is therefore advantageous to employ the most rapid plates with long focus camera objectives rather than slower plates and shorter focal lengths.

For the larger values of e ($0^{\mathrm{mm}}.015$) and the same values of r_0 and R_0 as before, we have for β_0,

		For $e = 0^{\mathrm{mm}}.015$	For $e = 0^{\mathrm{mm}}.01$
For $\left\{\begin{array}{l} s = 0^{\mathrm{mm}}.01 \\ \psi = \frac{1}{10} \end{array}\right.$ $\left\{\begin{array}{l} s = 0^{\mathrm{mm}}.015 \\ \psi = \frac{1}{15} \end{array}\right.$	$s\psi = 0.001$	$\beta_0 = \frac{1}{56}$	$\beta_0 = \frac{1}{37.4}$
For $\left\{\begin{array}{l} s = 0^{\mathrm{mm}}.015 \\ \psi = \frac{1}{10} \end{array}\right.$ $\left\{\begin{array}{l} s = 0^{\mathrm{mm}}.023 \\ \psi = \frac{1}{15} \end{array}\right.$	$s\psi = 0.0015$	$\beta_0 = \frac{1}{38.7}$	$\beta_0 = \frac{1}{25.8}$
For $\left\{\begin{array}{l} s = 0^{\mathrm{mm}}.02 \\ \psi = \frac{1}{10} \end{array}\right.$ $\left\{\begin{array}{l} s = 0^{\mathrm{mm}}.03 \\ \psi = \frac{1}{15} \end{array}\right.$	$s\psi = 0.002$	$\beta_0 = \frac{1}{29.4}$	$\beta_0 = \frac{1}{19.6}$
For $\left\{\begin{array}{l} s = 0^{\mathrm{mm}}.03 \\ \psi = \frac{1}{10} \end{array}\right.$ $\left\{\begin{array}{l} s = 0^{\mathrm{mm}}.045 \\ \psi = \frac{1}{15} \end{array}\right.$	$s\psi = 0.003$	$\beta_0 = \frac{1}{19.8}$	$\beta_0 = \frac{1}{13.2}$

In the case of stellar spectra the width of the slit is (theoretically) determined by the diameter of the first diffraction ring of the star image, and this in the case of most telescopes will not exceed $0^{mm}.01$ to $0^{mm}.015$. On account of the unsteadiness of the image due to atmospheric disturbances the width of the slit must, in order to avoid undue loss of light, generally be greater than this (as pointed out by Mr. Newall in his paper on the Bruce spectrograph, and previously by Professor Keeler and by the writer) but we cannot afford in general to make it more than $0^{mm}.02$. For this width of slit the maximum efficient aperture β_0 is about $\frac{1}{80}$ for $\psi = \frac{1}{10}$, and about $\frac{1}{40}$ for $\psi = \frac{1}{15}$.

In general, therefore, the focal length of the camera in the case of the stellar spectrograph should not be less than 30 to 40 times the linear aperture. If the spectrum is too faint and the time of exposure too long with this aperture, the proper remedy is to reduce the resolving power (and hence the linear dispersion) of the spectroscope train until the requisite brightness is attained. The great advantage of this method of procedure is that, for a given photographic result, the whole instrument is made smaller, simpler optically, and what is also important, less expensive, while the whole resolving power is practically utilized. The only disadvantage is the diminution in rigidity likely to be caused by the unusual focal length of the camera objective. This difficulty can however be completly overcome either (1) by diminishing the linear aperature a', the resolving power remaining constant; (2) by adopting one of the "fixed arm" forms which have been described and discussed in previous papers;[1] or (3) by adopting Mr. Newall's plan of using a telephoto lens. For an equivalent focal length of 30 to 40 apertures the last plan would have the disadvantage of greatly restricting the field and either the first or second would seem to be preferable. From the consideration of the relative advantages of small *vs.* large apertures the writer inclines to the first plan (or a combination of the first and second) in the case of the stellar spectrograph, in which the resolving power is low, and to the second plan in the case of the solar spectroscope. It is to be noted moreover that if the form of the spectroscope remains constant, the actual length of the camera remains constant for all values of β greater than β_0. For in order to maintain the photographic purity constant we must increase r in the ratio $\frac{\beta}{\beta_0}$, and therefore for similar instruments the linear aperture a' in the same ratio.

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[1] *Phil. Mag.*, October 1894, 337. *A. and A.*, December 1894, p. 835. *Ap. J.*, March 1895, p. 232, November 1895, p. 264 and December 1895, p. 370.

Hence

$$f' = \frac{a'}{\beta} = \frac{a_0}{\beta_0} = \text{Const.}$$

and the only advantage which the instrument of larger angular aperture has is a better proportion of parts.

It will be noticed that in considering the case of stellar spectra the assumption has been made that the slit image is uniformly bright across its whole width. This is not theoretically the case on account of the falling off in intensity at the edge of the diffraction image of the star. But except under the most exceptional conditions of seeing it is practically true on account of the size of the "tremor disk," as Mr. Newall aptly calls it, which is generally two or three times as large as the diffraction image of the star, and hence as the width of slit which it is thought desirable to use. It may be remarked in this connection that the existence and size of this tremor disk is one of the strongest arguments for that which I have so often before advocated, *i. e.*, the use of reflectors rather than large refractors for stellar spectroscopic work, for it makes the definition of the large object glass of comparatively little moment for this purpose. It seems a pity that the great light-gathering power of the large reflectors now in use should not be utilized in this most important and interesting field of research.

RYERSON PHYSICAL LABORATORY,
The University of Chicago,
February 1896.

ON THE VARIABLE STAR Z HERCULIS.

By N. C. Dunér.

In Vol. XVI, No. 6, of the *Astronomical Journal*, Mr. P. S. Yendell has published a quite extensive series of observations of the Algol-type star Z Herculis. Mr. Yendell has also made certain computations relating to its periodicity, but since he has given very little consideration to my paper[1] published in The Astrophysical Journal, April 1895, "On the Periodic Changes of the Variable Star Z Herculis," I deemed it desirable to make a comparison between Mr. Yendell's observations and the ephemeris which I have given on page 289 in the article above referred to. The results were as follows:

I. Even Minima

		Greenwich M. T.			*O. – C.*
1895.	July	30^d	17^h	52^m	$+22^m$
	Sept.	4	16	15	+28
	"	8	15	31	− 4
	"	20	14	53	− 8
	"	24	14	30	−20

II. Uneven Minima

		Greenwich M. T.			*O. – C.*
1895.	April	23^d	19^h	36^m	(-85^m)
	June	14	18	45	+15
	July	28	15	51	−34
	Aug.	5	16	18	+17
	"	25	14	56	− 7
	Sept.	2	14	15	−22
	"	10	13	52	−25
	"	22	13	47	+ 5

The mean deviation of these observations (omitting the obviously erroneous one of April 23) from the elements which I computed is therefore as follows:

Even minima - - - - - - $O. - C. = +2^m$
Uneven minima - - - - - $O. - C. = -7^m$

The agreement may consequently be regarded as complete, and it would be superfluous to repeat the computation until later observations are at hand. In the above comparison, as in the original computation, the reduction to the Sun has been negected.

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[1] An error of translation occurs in this paper on p. 286, line 21; for "daylight" read "the time of day."—Ed.

The observations of Mr. Yendell afford a very beautiful conirmation of the general correctness of my theory, which is all he more valuable since the circumstance that Mr. Yendell in observing used not my ephemeris, but Professor Hartwig's, proves that his observations were in no manner influenced by my computations. In only one particular do the observations of Mr. Yendell seem to conflict with my theory. According to Mr. Yendell the magnitudes of the stars were as follows:

At principal minimum - - - - - -	$7^m.94$
At secondary minimum - - - - -	$7\ .75$

The correctness of these figures is refuted by the following observations:

1. By the observations of myself and the assistant at this Observatory, Mr. Östen Bergstrand, supported by the photometric measures of Mr. Lindemann at Pulkowa. The results were:

Brightness at maximum - -	$6^m.89$	(Lindemann)
" at principal minimum	$8\ .05$	(Lindemann)
" at secondary minimum	$7\ .35$	(Dunér and Bergstrand)

2. By the observations of Hartwig in 1894. For if, at the beginning of Hartwig's observations of the secondary minima, the star had not been brighter than $7^m.75$, he could not possibly have arrived at the conclusion that the uneven minima occurred at a time of day so much earlier than the even minima as in fact he made it. If, on the other hand, my values for the brightness of the star at the secondary minimum are taken as correct, Hartwig, since he did not know that the minima differ in brightness, would certainly have been led to the conclusion that the uneven minima began about four hours earlier in the day than the even minima.

3. By the words of Mr. Yendell himself. He says, "The odd or secondary minima were found difficult of observation from the small range of the variation and the indefiniteness of phase." This would be a perfectly correct description of the appearance

TABLE I.

LINES PRODUCED BY A VACUUM-TUBE CONTAINING HELIUM.

Helium Wave-length	Intensity	Observer	Number of readings	Spectrum	Comparison Lines
D_3 5875.813	5	J.	2	II	5853.902, 5859.809, 5862.582, 5866.675, 5893.097 5905.895, 5916.475, 5919.860, 5930.406, 5934.881
D_3 5876 148	1	J.	2	II	
D_3 5875.815	5	J.	2	II	Same as above.
D_3 5876.150	1	J.	2	II	
D_3 5875.812	5	M.	2	II	5853.902, 5859.809, 5862.582, 5866.675, 5905.895, 5916.475, 5919.860, 5930.406.
D_3 5876.153	1	M.	2	II	
Ghost 3888.771		M.	2	II	3865.665, 3878.161, 3878.709, 3886.415, 3888.661 3903.087, 3905.661, 3920.398, 3923.038, 3928.059 3930.438, 3944.160.
3888.754	10	M.	2	II	
3888.851	2	M.	2	II	
D_3 3875.816	5	M.	2	II	
D_3 5876.132	1	M.	2	II	
*3888.656	0	J.	4	II	3886.415, 3888.661, 3903.081, 3905.661, 3920.396, 3923.038, 3928.059, 3930,438.
Ghosts 3888.771		J.	4	II	
3888.758	10	J.	4	II	
3888.859	1	J.	4	II	
D_3 5875.812	5	J.	4	II	
D_3 5876.151	1	J.		II	
D_3 5876.149	1	J.	8	II	Difference on plate exposed five hours.
D_3 5876.150	1	M.	10	II	
4026.325	3	M.	2	II	4005.399, 4030.900, 4033.213, 4034.631, 4045.964, 4063.751, 4071.896.
4026.500	0	J.	5	II	Difference on plate above.
D_3 5875.802	5	J.	2	I	2912.267, 2929.121, 2937.014, 2947.986, 2954.050, 2957.477, 2965.373, 2970.213, 2981.558, 2983.681.
D_3 5876.146	1	J.	2	I	
D_3 5875.802	5	M.	2	I	2912.267, 2929.121, 2937.014, 2997.986, 2973.347, 2983.681.
D_3 5876.130	1	M.	2	I	
D_3 5875.814	5	M.	2	I	Same as above.
D_3 5876.146	1	M.	2	I	

* It is uncertain whether this weak line belongs to helium or some impurity.

ON THE WAVE-LENGTH OF SOME OF THE HELIUM LINES IN THE VACUUM TUBE AND OF D_3 IN THE SUN.

By J. F. MOHLER and L. E. JEWELL.

THROUGH the kindness of Dr. W. W. Randall and Professor Ira Remsen we obtained the use of a tube filled with pure helium by Professor Ramsay, and have measured the positions of the D_3 lines. We used the second spectrum of a large concave grating ruled with 20,000 lines to the inch and of 21.5 feet radius. The comparison lines for the direct measurements were carefully selected solar lines. Several photographs were also taken and the comparison lines in these cases were principally iron lines in the arc.

As several other helium lines in the ultra-violet appeared on the same plates with D_3 they also were measured. One photograph was taken in the first spectrum with an exposure of three hours, another in the second spectrum with an exposure of five hours, and a third plate was given a two and one-half hours' exposure in the second spectrum. All these plates were taken at night when the building was perfectly quiet; and the definition is excellent, especially in the plate exposed two and one-half hours.

The plates were measured on the dividing engine used in the preparation of Professor Rowland's table of standard wave-lengths.[1] The method of measuring was the same as that used by Messrs. Humphreys and Mohler in their work on the effect of pressure on wave-length.[2]

Table I. gives the results of measurements made on the lines produced in the vacuum tube, the first part being the results of measurements with the eyepiece micrometer using solar lines for comparison. The wave-lengths of these lines are taken from the table of solar spectrum wave-lengths now being published in this JOURNAL by Professor Rowland. The second part of this table gives the result of the measurements of the II spectrum plates. The wave-lengths of the standards used are from the table published by Mr. Jewell in THE ASTROPHYSICAL JOURNAL, February 1896, p. 109. The last part of this table gives the results of the measurements of the I spectrum plate; and the wave-lengths of the standards here used are the means of all the measurements on these lines which were used in the preparation of Professor Rowland's table of standards without any correction having been applied to make them agree with the solar standards.

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[1] *A. and A.* 12, 1893; also *Ap. J.* 1, 2 and 3.

[2] *Ap. J.* 3, 118.

The observations marked *J* were made by Mr. Jewell and the those marked *M* by Mr. Mohler. Table II. gives the position of the D_3 lines in the chromosphere of the Sun and also in the neighborhood of Sun-spots. A large plane grating of 15,000 lines to the inch was used for this purpose.

Table III. gives the mean values of our measurements and also the values given for the same lines by Runge and Paschen.[1]

Table IV. is a list of all the lines in the solar spectrum in the vicinity of D_3. This table is the result of measurements on several plates of all the lines that can be seen, and differs slightly from the table of this region already published in THE ASTROPHYSICAL JOURNAL. It contains a few more lines and slightly more accurate positions for some of the lines, as a result of additional measurements. This shows lines agreeing fairly well in position with the two components of D_3, but it is probable that both of these lines are due, principally at least, to water-vapor.

The lines produced by the vacuum-tube were sharp and clear both when viewed directly and on the photographic plates, although in both cases the faint component was somewhat difficult to measure. In the chromosphere the lines were diffuse and broad, and the two components not easily separated; consequently the measurements on the faint component are little more than estimates. Directly over Sun-spots the lines were usually

[1] *Ap. J.* 3, January 1896.

faint, but near the spots (probably over the faculæ) the principal component was fairly dark and narrow and the faint component just visible, but too faint to measure, so that the measurements were made on the principal component alone. The two lines used for standards, although small, are sharp and clear and equally distant from D_3. During the two days upon which these measurements were made the air was very dry and the water-vapor lines in the neighborhood almost invisible. The wave-length of the principal component near Sun-spots is *less* than in the chromosphere. This might indicate an uprush of material at these places, or a lowering of pressure; this is the effect that might be expected over prominences. The difference in intensity of the two components of D_3 being so great, measurements upon it as a single line vary according as the cross-hairs of the instrument are set upon the middle of the line or upon the position of maximum intensity, therefore the personal equation of the observer enters quite largely into such determinations of its position. As a consequence of this the results of different observers as published vary greatly, and any such determination must necessarily be unsatisfactory. Mr. A. De F. Palmer in his article on D_3 in the *American Journal of Science,* **5**, 1895, giving the results of his measurements made at the Johns Hopkins University in 1893, claims an accuracy of 0.006 of an Ångström unit. The preceding considerations together with an examination of the original observations made jointly by Mr. Palmer and Mr. W. S. Day show that this claim of extreme accuracy is untenable.

We wish to thank Professor Rowland and Dr. Ames for the use of the instruments and plates used in these measurements, and Professor Remsen and Dr. Randall for the use of the helium tube.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
6456.070		0000	6474.330	A (wv)	000 N
6456.238		0000	6474.830	A?	0000 N
6456.603		3	6475.280	A (wv)	00
6456.872		0000	6475.435	A (wv)	00
6457.080		00 N	6475.846		2
6457.335	A?	0000	6476.046	A (wv)	0
6457.595		000	6476.584		0000
6458.770		0000	6476.795		0000
6459.115	A	000	6477.240		0000
6459.300	A	0000	6477.550	A (wv)	0000 d
6459.904	A	0000	6478.110		000 N
6460.210	A	0000	6479.408	A (wv)	00
6460.440	A	0000	6479.715	A (wv)	000
6461.154	A?	0000	6480.285 s	A (wv)	1
6461.345		0000	6480.475	A (wv)	0000
6462.060	A	0000	6481.220	A (wv)	000 N
6462.260	A	0000	6481.910	A (wv)	0000
6462.784 } s	Ca	5	6482.098		3
6462.965 }	Fe	3	6482.410		000
6463.188		0000	6482.690		0000
6463.334	A?	0000	6483.027	Ni	1
6463.475	A?	0000	6483.286	A (wv)	0000
6463.715	A (wv)	000	6483.468	A (wv)	1
6463.965	A?	0000	6483.677	A (wv)	0000
6464.170		0000	6483.975	A (wv)	0000 N
6464.398		0000	6484.170	A (wv)	00 N
6464.650	A (wv)	000	6484.694	A (wv)	0000
6464.897		00	6484.900	A (wv)	000
6465.630	A?	0000	6485.120	A (wv)	0000
6466.002		0000	6485.360		0000 N
6466.490	A	000 N	6485.790	A (wv)	00
6466.960	A	000 N	6486.495		0000 N
6467.212		0000	6487.005	A (wv)	0
6467.823	A	0000 N	6487.515	A?	0000
6468.120	A	000	6487.755	A?	0000
6468.590	A?	0000	6488.250	A (wv)	000 N
6469.050		0000	6489.350	A (wv)	00
6469.408		2	6489.870		0000 N
6469.593	A (wv)	0000	6490.595		0000 N
6469.860	A (wv)	000 N	6490.877	A (wv)	0000
6470.210	A (wv)	000 N	6491.015	A (wv)	1
6470.794		0000 N	6491.465		0000 N
6471.118		0000 N	6491.800		1
6471.522		0000	6491.876	Mn	000
6471.885 s	Ca	5	6493.130	A (wv)	0
6472.360		0000 N	6493.480	A (wv)	000
6472.700	A (wv)	00	6494.004 s	Ca	6
6472.823	A?	0000	6494.273		0000
6473.405	A (wv)	00	6494.530	A?	0000
6473.744		0000 N	6494.725	A (wv)	1

e-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
213 s	Fe	8	6517.925		0000
962		1	6518.245	A (wv)	00
082	A (wv)	2	6518.599 s	Fe?	2
340		0000	6518.973		0 N
688	Fe	2	6519.410	A (wv)	00 N
128	Fe	4	6519.682	A (wv)	1 N
840	A (wv)	00 N d?	6520.350		0000 N
407		0000 N	6520.983		0000 N
654		0000	6522.123	A (wv)	0000
168	Fe	1	6522.430	A (wv)	0000
437		000 N	6523.145		0000 N
880 s	Ca	4	6523.580	A (wv)	0000
122		0000	6523.907	A (wv)	0000
353		0000	6524.080	A (wv)	1
060		0000	6524.968		0000
440		000 N	6526.040	A (wv)	0000
901		0	6526.655		0000
425		0000 N	6526.888		0
747	A	0000	6527.444		1
114	A	0000	6527.825		0000 N
840	A?	0000 N	6528.340		0000 N
415	A (wv),-	0	6528.777		00
700		0000	6529.415		0000 N
053		0000 N	6530.247		0000
710		0000 N	6530.845	A (wv)	00
560		0000 N	6531.311		0000
340		0000 N	6531.667		000
890	A (wv)	0000 N	6532.595 s	A (wv)	1
380		0000	6532.800		0000
826	A (wv)	0	6533.110	Ni?	0
080		00	6533.330		0000
845		000	6533.763		0000 N
410		0000 N	6534.172 s	-,A (wv)	2
679		0000	6534.470		0000
240	A (wv)	00	6534.875	A (wv)	0000
470	A (wv)	00	6535.210		0000
145	A?	0000	6536.212		0000
300		0000	6536.955	A (wv)	00
847	A	0000 N	6537.480		0000
185	A?	0000	6537.666		0000
530	A (wv)	000 N	6538.170		000 Nd?
956	A (wv),-	2	6538.770	A?	000 Nd?
456		0000	6540.665	A?	000 N
080	A (wv)	000	6541.510	A?	0000
311 s		2	6542.550	A (wv)	00
634		0000	6543.280	A?	0000 N
750	A (wv)	1	6544.140	A (wv)	2
855	A (wv)	2	6546.030	A (wv)	000 N
315	A (wv)	0	6546.479 s	Ti-Fe	6
657		0000	6547.945	A (wv)	0

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
6548.855	A (wv)	1	6583.787	A (wv)	0000
6549.290	A?	0000	6583.967		00
6550.515	A?	0000	6584.550	A?	0000
6551.940		000	6584.797	A?	000
6552.275		0000 N	6585.470	A (wv)	0000 N
6552.865 s	A (wv)	1	6585.763	A?	000
6554.025	A (wv)-	00 Nd?	6585.950		0000
6554.470	Ti	0	6586.550	Ni	1
6555.080		0000 N	6586.764	A (wv)	000
6555.700		1 N	6586.935	A (wv)	0000
6556.087		0000	6587.864		00 N
6556.308	Ti, A (wv)	1	6588.828	A (wv)	0000 N
6556.558		0000	6590.245		0000 N
6557.046	Fe?	0	6591.575	Fe?	00
6557.408	A (wv)	0	6591.833		0000
6558.095	A?	0000	6592.076		0000
6558.392	A (wv)	00 N	6592.372		0000
6558.830	A?	0000 N	6592.770	Ni	00
6559.193		0000	6593.161 s	Fe	6
6559.815		0	6594.121 s	Fe	4
6560.045		0000	6594.600	A (wv)	000
6560.307		0000	6595.590		0000
6560.490		0000	6596.135		000 N
6560.800	A (wv)-	1 Nd?	6597.273		0000 N
6561.335		000	6597.807	Cr	1
6563.045 s C[1]	H	40	6598.552		0000 N
6563.763	A (wv)	000	6598.848	Fe?	0
6564.305	A (wv)	00	6599.131		0000
6564.450	A (wv)	0	6599.353	Ti	00
6565.083	A?	0000 N	6599.570	A (wv)	000
6565.783	A?	000	6599.925		0000
6566.075	A?	0000	6602.370	A (wv)	0000Nd?
6569.040	A (wv)	000 N	6603.601		0000 N
6569.460 s	Fe	5	6604.837		1
6570.103		0000 N	6605.810		000
6570.965		0000 Nd?	6606.160		000 N
6571.436		0000	6607.215		00 N
6572.330 s	A (wv)	1	6607.586		0000 N
6573.030	Ca?	1	6608.280		0
6573.765		0000 N	6609.360 s		3
6574.468 s		1	6609.818		00
6574.707		0000	6609.929		000
6575.085 ⎫ s	A (wv)	1	6610.315		0000
6575.270 ⎭	Fe	2	6610.990		0000
6576.615		000 Nd?	6611.612		0000
6577.131		0000	6612.474		000
6580.470	A (wv),-	00 N	6612.790		0000
6581.025	A (wv)	00	6613.675		00 N
6581.452		0	6614.045	Ni	00 Nd?
6583.505	A?	0000	6617.267		000 Nd?

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[1] The width of C is 0.963; and that of the extreme shading is 1.240. C is either faintly double or reversed in the Sun.

ength	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
0		000 N	6657.205		000 N
6		0000 N	6657.878		000
5		000 N	6659.164		0000
1		0000 N	6660.105		000
9		0000 N	6660.830		0000
1		0000 N	6661.320	Cr	00
5		0000 N	6661.580		000
7		0000 N	6662.011		0000 N
6		0	6662.819		0000 N
4		0000	6663.487 s		1
7	Fe?	0	6663.701 s	Fe	3
2		000 N	6664.030		0000 N
0		000 N	6664.550		0000 N
8		0000	6665.420		000 N
4		0000	6665.998		0000
0	Cr	000	6666.780		000 N
5		000 N	6667.695		000
1		0000	6667.980	Fe?	00
7		000	6668.640		000 N
0		00 N	6669.041		0000 N
5		0	6669.550		000 N
5 s	Fe	2	6672.915		0000
1		0	6678.235 s	Fe	5
1		0000 N	6678.817		0000
5	Ni	0 N	6679.090		000 N
0		0000	6680.396		000
0		00 N	6680.864		0000
0		0000 N	6685.131		0000
4		0000	6687.750		0000
5		0000 N	6691.067		000 N
5		0	6692.547		000 N
5		00 N	6693.099		000 N
0		0000 N	6695.886		0000 N
7		0000 Nd?	6696.275		1 N
0 s	Ni	5	6696.565		00
2		0000	6697.070		0000
0		000 N	6697.650		000 N
5		000 N	6698.336		0000 N
0		0000	6698.913		0
5		00	6699.380		00
5		0000	6701.163		0000
0		000	6701.621		000
0		0000	6703.820 s		1
		0000	6704.286		0000 N
0		0000 N	6704.745		000
5		0000	6705.352 s		1
5		00	6705.753		0000
0		0000	6705.942		0000
0		000 N	6707.695		000
0		0000	6708.176		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
6709.226		0000 N	6743.826		000 N
6710.182		0000 N	6745.364		00
6710.570		0	6745.798		000 N
6710.789		0000	6746.235		00
6711.529		0000	6747.226		000
6712.094		000 N	6747.812		0000 N
6712.714		000 N	6748.390		000
6713.290		1	6748.686		0000
6713.454		000	6749.029		000
6713.993		1	6749.120		000
6715.635		1	6749.791		0000 N
6716.500		0	6750.033		0000 N
6716.914		000 N	6750.407 s	Fe	3
6717.775		000	6751.690		0000
6717.940 s	Ca	5	6752.965 s	Fe	1
6719.880		000 N	6753.265		000 N
6721.020		0000 N	6753.720		000 N
6722.096 s		2	6754.233		0000
6722.959		0000 N	6755.189		000
6724.935		000 N	6755.855		0
6725.219		0000	6756.818		000 N
6725.615	Fe	0	6757.445		00 Nd?
6725.960		0000	6757.909		0000 N
6726.539		0000	6759.146		000 Nd?
6726.925 s	Fe	2	6761.260		000 Nd?
6728.922		0000	6761.852		0000Nd?
6729.270		00	6762.405		0000 N
6729.996		000 N	6762.647		000
6730.558		000 N	6763.549		0000 N
6732.320		00	6763.939		0000 N
6732.921		0000	6764.330		000 Nd?
6733.410	Fe	1	6767.602		0000Nd?
6733.783		0000 Nd?	6768.028 s	Ni	4
6734 524		000 N	6768.248		0000
6735.277		0000	6769.930		000
6735.708		000 N	6771.310	-, Co	0 d
6736.099		0000 N	6771.789		0000
6736.798		000	6772.152		0000
6737.619		0000 N	6772.568 s	Ni	2
6738.230		0	6775.047		0000 N
6738.485		00	6776.595		0000 N
6739.080		00 N	6777.653		00
6739.370		0000	6778.022		0000 N
6739.775		0	6781.172		0000 N
6740.244		0000	6782.061		0000 N
6741.268		0000	6782.465		000 N
6741.880		0 N	6782.748		0000 N
6742.535		0000	6783.609		0000 N
6742.816		0000 N	6783.960		00
6743.381	Ti	1	6784.460		000 N

-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
06		000 N	6820.630 s	Fe	2
10		000 N	6820.987		0000 N
.50		0000 N	6822.293		0000 N
06		000 N	6825.108		000 N
00 s	Fe	1	6827.529		0000
50		0000 N	6828.215		000 N
.00		000 N	6828.445		0000 N
76		0000	6828.850 s	Fe	2
06		000	6829.293		0000
69		0000	6829.832		0000
33		000	6831.098		0000
77		0000	6831.730		0000
88		0000 N d?	6832.727		0000
20		00	6833.501		00
75		0 N	6833.845		0000 N
19		0000	6835.622		0000 N
60		000	6836.956		0000 N
70		000	6837.268		0
75		000 Nd?	6838.612		0000 N
45		000 N	6838.980		00
75		0	6839.088		0
37		000 N	6840.086		1
61		0000	6840.698		0000 N
10		0000	6841.598 s	Fe	3
15		00	6841.897		0000 N
36		0000 N	6842.294		0
65		0000	6842.624		0000 Nd?
55		00 N	6842.945		1
50		0000 N	6843.420		000 N
97		0000	6843.913 s	Fe	3
02		0000	6844.939		0000
58	Fe	0	6845.937		0000
45	Fe	0	6847.860		000
26		0000	6848.468		0000 N
54		000	6848.823		0 Nd?
00		0000 N	6849.559		000 N
93		0000 N	6850.110		0000 N
03 s	Fe	1	6850.696		00 N
30		0000 Nd?	6851.309		0000 N
41		0000 N	6851.910		000
17		0000 N	6852.980		000
78		0000 N	6854.109		0000
19 s	Fe	3	6854.590		000
05		000 N	6854.796		0000
65		000 Nd?	6855.105		00
60		0000 N	6855.419 s	Fe	3
10	Co	0	6855.700		0000
03		0000	6855.990		0
45		00 Nd?	6856.290		0000
98		000 Nd?	6857.515		0

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
6857.773		0000 N	6875.415		0000 N
6858.109		0000 N	6875.830 s	A (O)	13
6858.415		2	6876.255		000 N
6858.661		0000	6876.595		000 N
6858.863		0000	6876.958 s	A (O)	13
6859.227		0000	6877.440		0000Nd?
6859.752		0000	6877.882 s	A (O)	12
6860.007		000	6878.342		0000 N
6860.358		0000	6878.570		0000Nd?
6860.590		000	6878.800		0000 N
6861.044		0000	6879.288 s	A (O)	12
6861.213		000	6879.528		0000
6861.529		0000	6879.784		000
6861.770	Ti?	000	6880.040		0000
6862.014		0000	6880.172 s	A (O)	6
6862.210		0	6880.455		0000
6862.431		0000 N	6880.887		00
6862.760		1	6881.305		0000 N
6863.119		0000	6881.720		00
6864.048		0000	6881.983 s	Cr	0
6864.585		000	6882.784 s	Cr	1
6864.775		0000	6883.325 s	Cr	1
6865.206		0000	6883.635		0000
6865.704		0000	6884.076 s[3]	A (O)	10
6865.906		000	6884.656		0000 N
6866.243		0000	6885.221	A?	0000
6866.604		000 N	6885.598	A?	0000
6867.037		0000 N	6886.000 s	A (O)	11
6867.457 s[1]	A (O)	6d?	6886.446	A?	0000 N
6867.631	A	1	6886.990 s	A (O)	12
6867.800 s	A (O)	5	6887.242		000
6868.092 s	A	0 Nd?	6887.444		000
6868.336 } s	A (O)	6	6887.765	A	000 Nd?
6868.478 }	A (O)	6	6887.969	A	000
6868.645 } s	A	1	6888.250	A	000
6868.795 }	A	3	6888.670		0000
6869.142 s	A (O)	7	6888.830		0000
6869.353 s	A (O)	6	6889.192 s	A (O)	13
6869.850	A?	00	6889.490		000
6870.116 } s[2]	A (O)	7 } d	6889.827		0000Nd?
6870.249 }	A (O)	7 }	6890.151 s	A (O)	14
6870.853	A?	000 N	6890.460		000
6871.180 s	A(O)	8	6891.000	A	000
6871.532 s	A (O)	10	6891.180	A	000
6872.105	A ?	000	6891.617		0000 N
6872.486 s	A (O)	11	6891.843	A	000
6873.080 s	A (O)	12	6891.970	A	0000
6873.630	A?	0000	6892.618 s	A (O)	14
6874.037 s	A (O)	12	6893.099		000
6874.899 s	A (O)	13	6893.560 s	A (O)	15

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[1] First line in the head of the B group, due to atmospheric oxygen. [2] Principal line in the head of the B group. [3] First line in the tail of the B group.

length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
8		0000 N	6913.810		0000
0		0000 N	6913.945		000
0	A	000	6914.158		0000
0	A?	000 N	6914.337 s	A (O)	11
0		000 N	6914.668		0000
7	A?	0000	6914.823 s	Ni	4
9s	A (O)	14	6915.075		0000 N
0		0000 N	6915.270		0000 N
2		0000	6915.775	A	000 N
8 s	A (O)	15	6916.136	A	000 N
3		0000 N	6916.325		0000 N
7		0000 N	6916.743	A	0000 N
0	A?	000 N	6916.948 s		2
6		00	6917.235		000 N
6		0000 N	6917.710	A	000 Nd?
0		0000 N	6918.015		0000
0		0000	6918.370 s	A (O)	9
9 s	A (O)	14	6918.655	A?	000
4		000 N	6918.860		0000
7 s	A (O)	15	6919.250 s	A (O)	9
7		0000	6919.556	A	000
0		000 N	6920.430		00
5		0000	6920.650		0000
3		0000	6921.135	A?	0000
1		0000	6921.615	A?	000
0		00	6921.834	A?	0000
2 s	A (O)	14	6922.238	A?	000
5		000	6922.548	A?	0000
3		0000	6922.735	A	000
1 s	A (O)	14	6922.912		0000
0		000	6923.553 s	A (O)	9
5		0000	6924.080	Cr?	0000 N
5	A	000	6924.427 s	A (O)	9
0		000 Nd?	6924.713	A	000 N
2	A	000	6925.134	Cr?	0000 N
0	A	000	6925.543		1
0		0000	6925.752		0000
3 s	A (O)	13	6926.170		0000
1		0000 N	6926.363		0
6 s	A (O)	13	6926.660		0000
0		0000 N	6926.850		000
0	A?	000 N	6927.020	A	00
4		0000	6927.520	A?	000
0	A	000 N	6927.948		0000
0	A,-	00 N	6928.500		000
3	A	000 N	6928.796		0000
0		0000 N	6928.977 s	A (O)	4
8	A	000 N	6929.227	A?	0000
4	Ti?	0000	6929.375	A	000
8 s	A (O)	11	6929.560	A (wv)	00

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
6929.840 s	A (O)	4	6943.379		0000
6930.075	A	00	6943.689		0000
6930.185	A	000	6943.904		0000
6930.600		0000 N	6944.060	A (wv)	3
6930.890		00 N	6944.510		0000
6931.355		0000	6944.861		0000
6931.575	A	00 N	6945.135		0000
6932.012	A	00	6945.477		4
6932.298		0000	6945.745		0000 N
6932.445	A	00	6946.160		000 N
6932.765		0000	6946.638		0000
6933.024		0000	6946.860	A (O)	0
6933.305		0 N	6947.191		0000 N
6933.469		0000	6947.406		0000
6933.715		000	6047.702	A (O)	0
6933.887		2	6947.782 s	A (wv)	5
6934.075	A (wv)	2	6947.863	A wv	00
6934.325		0000	6948.146		0000 N
6934.468		0000	6949.240	A (wv)	1
6934.670 s	A (O)	2	6949.310	A (wv)	1
6934.870		000	6950.188		0000 N
6935.153		0000	6951.010	A (wv)	1
6935.355	A?	000	6951.518		1
6935.530 s	A (O)	2	6951.900	A?	000
6935.704	A?	0000	6952.593	A	000 N
6936.075	A	000 N	6953.337	-,A (O)	00 N
6936.290		0000	6953.828 } s	A (wv)	1
6936.755		000 N	6954.020 }	A (wv)	00
6937.122		0000	6954.147	A (O)	000
6937.420		000 N	6954.718	A ?	0000 N
6937.957	A (wv)	2 N	6955.307		00
6938.195		000	6955.507	A	0000
6938.520	A (wv)	1 N	6955.915	A (wv)	000 N
6938.727		000	6956.660 } s	A (wv)	4
6939.050		000	6956.746 }	A (wv)	1
6939.460		0000	6957.675	A	000
6939.875	A (wv)	2	6957.985		0000
6940.030		0000	6958.753	A?	0000
6940.270		0000	6959.704 s	A (wv)	3
6940.436	A (wv)	2	6960.105	A (O)	000 N
6940.625	A (O)	1	6960.590		00
6940.861		0000 N	6960.880	A (O)	0000
6941.023		0000	6961.136		0000
6941.260	A (wv)	000 N	6961.515 s	A (wv)	4
6941.475	A (O), A (wv)	1	6962.075		0000 N
6941.979		0000 N	6962.213		0000 N
6942.402	A (wv)	2	6963.100		000 N
6942.630	A (wv)	1	6963.900	A	000 N
6942.746		0000	6964.447		0000
6943.083		000	6964.812	A (wv)	1

-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
20	A	000 N	6992.065	A	000 N
16		00	6992.571		0000
58		000	6993.145	A	00 N
54		0000	6993.776	A (wv)	2
37		0000	6994.360	A (wv)	1
02		0000	6994.635		0000
63	A	00	6994.880	A	00
35	A (wv)	0	6995.260		0000
00		0000	6996.930		0000
72		000	6997.420	A?	0000
05		00	6998.070	A?	0000
132		0000	6998.283	A	00
43	A	0000 N	6998.500		0000 N
00		0000	6998.978 ⎫ s	A (wv)	0
96	A?	000 N	6999.223 ⎭	A (wv)	2
06		0	6999.488	A	0000
76		0000	6999.823	A	0000
35		000 N	7000.155 s		1
83		1	7000.411		0000
198		00	7000.555		0000
15	A (wv)	3	7000.880		00
138		0000	7001.125	A	000
10		0000	7001.475		0000
70 s		1 N	7001.810		00
120		2	7002.385	A	00 N
20	A	000 N	7002.870		0000 N
10		0000	7003.837		1
60		1	7004.240		0000 N
20	A?	0000 N	7004.575	A (wv)	0 N
196		000	7004.995	A (wv)	2
22	A (wv)	1	7005.365	A (wv)	0 N
60	A?	000	7005.608	A	0000
01		000 N	7005.850	A	000
80		0000 N	7006.157 s		1
10		000 N	7006.420	A	000 Nd?
80		0000 N	7006.915	A	000
70		0000	7007.140		0000 N
20	A (wv)	0 N	7007.385	A	0000 N
76		0000	7007.970	A	000 N
80	A	000	7008.225		0
33 s	A (wv)	3 N	7008.515	A	00 N
125	A (wv)	0 N	7008.920	A?	0000
36		0000 N	7009.485	A	000 N
05		0	7010.135	A (wv)	0 N
75		0000	7010.618		000 N
37 s	A (wv)	3	7010.920	A	0000 N
25		000 N	7011.230	A	000 N
30	A?	0000	7011.590 s	A (wv)	2
32	A (wv)	1	7012.130		0000
95	A	000	7012.490	A	0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
7012.880		0 N	7037.800	A	1
7013.550		000 N	7038.061		0000
7014.080		000	7038.202		0000
7014.810		0000 N	7038.500 s		1
7015.260		000	7039.040		0
7015.560	A	000 N	7039.560	A	0 N
7015.800		0000 N	7040.053 s		1 N
7016.176		0000	7040.861		0000
7016.330 s	-,A (wv)	1	7042.025		00 N
7016.675 s	-,A (wv)	3	7042.745		0000
7017.020		000 Nd	7044.265		0000 N
7017.575	-,A	00 Nd	7044.777		000
7017.935		0	7044.952		00
7018.250		0000	7045.313		000
7019.043	A	000	7045.517		0000
7019.620	A	0	7046.056		0000
7020.445	A?	0000	7047.133		00
7020.900	A	000	7047.631		000
7021.100	A	000	7048.291		0000
7021.790	A	0000	7049.273		0000
7022.302		0000	7050.783	A?	000
7022.662		000	7051.115		0
7022.810	A	000	7052.030	A?	0000 N
7023.230 s		2	7052.665	A?	000 N
7023.550		0000	7053.070		1
7023.770 s	A (wv)	2	7053.191	A?	0
7023.983		0000 N	7053.755		0000 N
7924.310		0	7054.280		000 N
7024.660		0000	7054.970	A	00 N
7024.913 } s		1	7056.210		00 N
7025.140	A	0	7056.750		0000
7026.660	A	00	7057.260	A	0 N
7026.890		0000	7057.590		0000
7027.213 s	-,A (wv)	0	7057.820		0000
7027.740 s	-,A (wv)	2	7058.186		0000
7028.115	A	0	7058.490	A?	000
7028.466		0000	7059.825		0000 N
7028.860		0000 N	7060.314		0000
7029.260	A	0	7060.725		1 N
7029.390		00	7061.780	A	00 N
7029.975	A	0000 N	7062.265		0000
7030.295		0	7062.750		0000
7030.657		0000	7063.255		000 N
7031.215	A	00 N	7063.770	A?	0 N
7032.585		1	7064.400		0000
7034.360	A?	0000 N	7064.917	A?	000
7034.670	A	0000 N	7065.496		0000
7035.170 s		2 N	7065.920		1
7036.129		0000	7066.495		000 Nd?
7037.465	A	0	7067.210		00 N

-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
42		000 N	7097.395		000 N
65		000 Nd?	7097.940		0000
85		2	7099.219		0000 N
70		000 N	7099.812		0000 N
50		0000 N	7100.415		000 N
20		0000	7100.960		0000 N
34		0000	7102.222		0000 N
30		0 N	7102.560		000 N
20		000	7103.430		000
70		0000	7105.422		0000
90		000 N	7106.434	A?	000 Nd?
57		0000 N	7107.300		0000 N
88		0000	7107.740		0
75		0000	7108.187		0000 N
87		0000	7108.387		0000 N
09		000 N	7109.310	A	000 Nd?
40	A?	00 N	7110.700		0000 N
30		000 N	7111.180		1
85		0000	7111.730	A	000 N
70		000 N	7112.199	A	0000
10		000	7112.450		0
45		0000 N	7113.010		0000 N
55		0000 N	7113.455	A?	00 N
04		0000 N	7113.700		0000
80		00 N	7113.870		0000
93		000 N	7114.313	A?	0000
35		000 N	7114.447	A?	0000
31		0000	7114.860		000
20		0000 N	7115.444	A?	000
65		2 N	7115.591	A?	0000
10		0000 N	7116.670		0000 N
90		0000	7117.240		000 Nd?
08		00	7117.549		000
50		0000 N	7117.948		0000 N
99		0000 N	7118.390	A?	000
30	A?	00 N	7118.554	A	1
00		0000 N	7119.254		0000
60		2	7119.955		000 N
30		0000	7120.320		000 N
40		000	7121.965		0000 N
20		000 N	7122.484		4
20		0000	7123.000	A?	0000
95		000	7125.269	A?	0000
09		0000	7126.414	A?	0000
05		0000	7127.087		0000 N
15		0000	7127.845		0 N
95		0000 N	7128.390	A?	000 N
90		0	7128.810		0000 N
40		000	7129.410	A?	0000 N
60		0000	7130.140		0000 N

Wave-length	Substance	Intensity and Character	Wave length	Substance	Intensity and Character
7131.204		3	7164.725[1]	-, A	2
7131.650		000 N	7165.018		000 N
7132.043	A?	0000	7165.396		0000 N
7133.263		1	7165.845	A,-	1 N
7133.660		000 N	7166.355	A	000 N
7134.423	A	00 N	7166.553	A	0000
7136.120		000 N	7166.931		0000
7137.720	A	1 N	7167.305	A	000 Nd?
7138.209	A?	0000 N	7167.645	A	00
7139.215		000	7168.170	-,A	4 N
7139.973		0000 N	7168.465	A	0000
7140.568	A	000 N	7168.748	A	0000
7141.360	A	0000	7169.017	A	0000
7141.930		0000 N	7169.355	A?	00
7142.451	A	0000 N	7170.162	A?	0000
7142.800		0	7170.360	A	00
7143.257	A	1	7170.619	A?	0000
7143.660		0000	7170.833	-,A	1
7144.229		0000	7171.130	A	0000 N
7145.022	A	0000	7172.250	A	300 N
7145.615		1	7172.970	A,-	1
7147.939	A	2 N	7173.200		000 N
7148.435		3 N	7173.675	A,-	2
7148.793		0000	7174.040	A	0
7148.995		000 N	7174.440	A	0
7149.574		0000	7174.930		0000 N
7150.100	A?	0000	7175.580	A?	0000 Nd
7150.450	A?	0000 N	7176.225	A,-	1
7150.947	A	1	7176.430	A	1
7151.442	A	1	7176.719		0000
7151.765		00	7177.170	A	0
7152.375		0000	7177.390	A	0
7153.627	A?	0000	7177.640	A,-	2
7154.030		0000	7177.915	A	2 N
7155.014		0000 N	7178.090	A	00 N
7155.945		0 N	7179.060		0000
7156.700	A	1 N	7179.570	A	000
7157.438		0000	7179.910		0000 N
7158.084	A?	0000	7180.300	A	000
7158.790		000 N	7181.500	A	0
7159.045	A	0 N	7181.790	-,A	2
7159.590	A	00 N	7182.045	A	1
7160.602		0000 N	7182.260	A?	00
7161.154		0000 N	7182.658	A	0000
7161.746		0000 N	7183.089	A	0000
7162.352	A	00 N	7184.650	A	3
7162.630		000 N	7184.785		4
7163.012		0000	7185.205		000 N
7163.469		0000	7185.580		0000 N
7164.125	A?	000 N	7185.870		0000 N

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[1] This is the beginning of the "a" group; most of the atmospheric lines are produced by water vapor, but as the identification is somewhat uncertain in many cases and as some of the lines may be due to other atmospheric gases, they have simply been marked A.

e-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
.405	A	4	7209.780	A,-	3
.655	A	5	7210.679	A	000 N
.280	A	2	7211.473	A	1
.645	-,A	5 N	7212.308	A	000 N
.286		0000 N	7212.740	A	00
.875		0000 N	7214.166	A	000
.242	A	0000	7215.042	A,-	000 N d
.445	A	00	7215.782	A?	000 N
.740		0000	7216.482	A	000
.159		000	7216.791	A,-	2
.427		000	7216.927	A?	0000
.755	A,-	6 N	7217.479		0000 N
.150	A	2 N	7218.323	A	000 N
.745	A	1 N	7218.799		000 Nd
.039		0000	7219.337	A	0000 N
.475	A	000 N	7219.987		0
.835	A	3	7220.306	A	0000 N
.040	A	3	7221.088	A	0000 N
.655		0000	7221.492		0
.871		0000	7221.870	A?	0000
.290	-,A	2	7222.691		000 N
.827		0000	7223.216	A	00 N
.070	A	0 N	7223.930 s	A	3
.716	A?	0000 N	7224.414		0000
.300	A	0	7224.791		000 N
.515	A	1	7225.356		0000
.698	A	000	7226.522	-,A	000 N
.145	A	1 N	7227.781 s		3
.705	A	2	7228.468	A?	0000
.152		0000 N	7229.013	A?	000
.095		000	7229.424		0000
.378		0000	7232.520 s	A	1
.665	A	2	7233.170 s	A,-	3
.800	A,-	4	7234.688	A	0
.460	-,A	4	7235.011	A	2
.728	A	0	7235.658		000 N
.485		1 N	7236.142		000 N
.843		0000	7236.418	A	1
.138		0000	7236.695	A	00
.135	A	2	7238.216	A	0000 N
.577	A,-	5	7239.281	A	0000
.672		00	7239.765		0000
.022		0000	7240.149	A	1
.692	-,A	6	7240.883 } s	A	3
.165		0000	7241.099 }	A	2
.415		00	7243.750 } s	A	1
.715		1	7244.004 }	A	2
.079		0000	7245.152		00
.511		0000	7245.959	A	2
.427		0000	7246.457		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
7247.091		0000	7277.469	A	000
7247.494 s	A	1 N	7277.678		2 N
7248.047		0000 N	7278.385	A	0 N
7249.244	A	0 N	7278.762	A?	000
7249.581		0000	7280.042	A	00 N
7250.511	A	1 N	7280.890	A	00 Nd
7250.928		00 N	7281.913		0000 N
7252.032		000 N	7282.600	A	1 N
7252.355	A	0	7283.112		000 N
7252.664	A	2 N	7283.435	A	000
7253.137	A	00	7284.107		0000 N
7253.493	A	1	7285.158		00
7254.002	A	1	7285.576	A	000
7254.576		0000	7286.249		0000 N
7254.940		000	7286.828		0000 N
7255.586		0000	7287.673 s	A	2 N
7256.422		000	7288.073	A	0000 N
7257.392	A	000	7288.416		1
7257.674	A	00	7289.049		00
7258.226	A	1 N	7289.466		0 Nd?
7258.939		0000 N	7290.087	A	00 N
7259.357		0000 N	7290.686 s	-,A?	3 N
7259.895		0000 N	7291.366	A	0 Nd?
7260.462	A	000 Nd?	7291.757	A	00
7261.028	A	0	7292.025		0000 N
7261.310		0000	7292.409	-,A	0 N
7261.808	A?	00 N	7293.009	-,A	0 N
7262.260	A	1	7293.372	A	000 N
7262.576		0000	7293.655	A	00
7263.277	A	000	7294.166		0000 N
7263.640	A	0000	7294.651	A	00
7264.125		0000	7295.042	A	000
7264.676	A	00	7295.325	A	1
7264.892 s	-,A	2	7295.903	A	00 N
7265.431		0000 N	7296.536	A	00
7265.868 s	-,A	5	7299.917 } s	A	0 N
7266.441		0000 N	7300.226 }	A	1 N
7267.101		0000 N	7300.846		000 N
7268.865		0000 N	7301.169		0000
7269.566		0000 N	7301.599		0000
7270.065 } s	A	00 N	7301.801		0000
7270.414 }	A	000	7302.394	A	00
7273.255 s	A?,-	5 N	7302.906	A	000 N
7273.941		0000 N	7303.162	A	0000
7274.952		0000 N	7303.485		2
7275.675		2 N	7304.078		0000 N
7276.083	A	000 N	7304.468 s	-,A	3 N
7276.581	A	00	7305.195	A	0000 N
7276.810	A	00	7306.878		00
7277.146	A	00	7307.282		0000 N

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
7308.253		00 Nd?	7316.223	A	000 N
7309.047	A	1	7317.112	A	00 N
7309.788	A	2 N	7317.611	A	0 N
7310.474	A	00	7318.405	A	00
7311.403	-,A	0 Nd?	7319.015	-,A?	1
7312.279		0000	7321.030 s	A	1 Nd
7312.911	A	1	7324.249	A	1
7313.504	A	000 N	7326.462		0
7314.797	A,-	000	7327.750	A	1
7315.416		0000 N	7331.225 s		1 N
7315.834	A	0			

MINOR CONTRIBUTIONS AND NOTES.

THE EFFECT OF A TOTAL ECLIPSE OF THE SUN ON THE VISIBILITY OF THE SOLAR PROMINENCES.

IN his recent valuable report on the total solar eclipse of April 16, 1893,[1] Professor J. M. Schaeberle sums up his conclusions with regard to the prominences in the following words: "All visible matter exterior to the Sun's surface is apparently in rapid motion, the path described corresponding to one of the conic sections. The so-called stationary prominences are probably stationary as to the general form only, the matter — which remains visible so long as the density is sufficiently great — in the same being in rapid motion. I have carefully compared the eclipse photographs taken with the 40-foot telescope on April 16, 1893, with the best spectroscopic observations accessible (both visual and photographic), taken of the uneclipsed Sun on the same day, and the result briefly stated is that while the coarser features of the Sun's surroundings are shown in spectroscopic observations of the uneclipsed Sun, *the finer and essential details are wanting.*" On another page (93) Professor Schaeberle concludes, from a comparison of his eclipse photographs with the visual and photographic results obtained by Herr Fényi and myself on the same day at Kalocsa and Chicago, that the reason this structure of the prominences has not been more generally recognized is "the want of sufficient scale and definition." As Professor Schaeberle's photographs of the corona and prominences are undoubtedly superior to any obtained at previous eclipses, he is in possession of the very best of data for a study of the question. The importance of the subject has, however, seemed to me sufficient to warrant a further brief reference to my own observations, in connection with a review of certain other investigations made at various total eclipses since 1870.

The extensive series of observations made by Professor P. Tacchini at the eclipses of 1870, 1882, 1883 and 1886 are of great importance in connection with the work of Professor Schaeberle, and as they are not referred to by him, and seem to have been overlooked in many dis-

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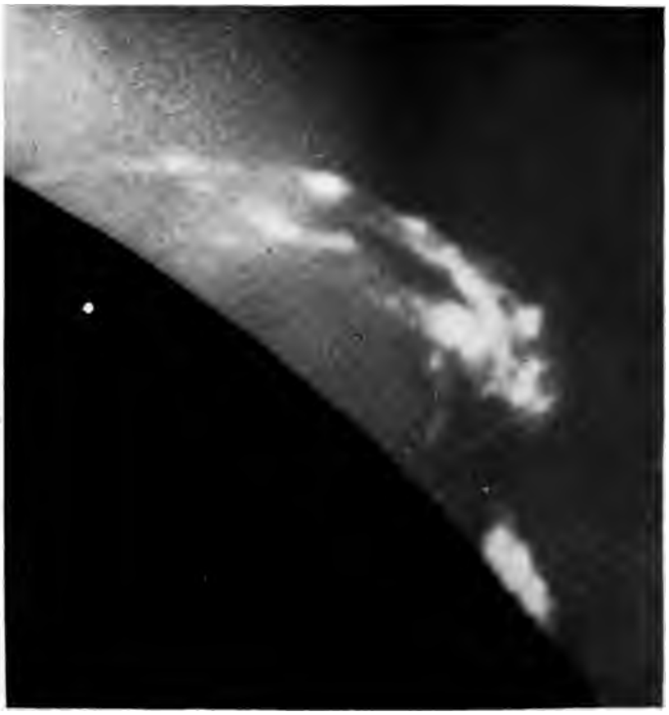
[1] *Contributions from the Lick Observatory, No. 4,* p. 125.

PLATE XXV.



PROMINENCE PHOTOGRAPHED BY PROFESSOR
J. M. SCHAEBERLE DURING THE TOTAL
ECLIPSE OF 1893, APRIL 16.

cussions of the nature of prominences, I have brought together below some of the most remarkable results.[1]

The eclipse of 1870 was observed by an Italian party stationed at Terranova, Sicily. During the total phase drawings of the prominences were made by Messrs. Legnazzi and Müller, which agree closely as to their general form. These were compared by Professor Tacchini with drawings of the prominences made with the spectroscope immediately after totality, with the following result: "Da questo confronto ci pare di potere arrivare alla seguente conclusione, che cioè durante gli eclissi totali di sole le protuberanze, che allo spettroscopio si mostrano tutte composte di parti ben distinte e frastagliate, si presentano invece sotto forma di masse compatte o nebulose, la cui forma si addatta però all'ossatura o scheletro che noi vediamo allo spettroscopio; di modo che se le osservazioni spettroscopiche sono fatte prima dell'eclisse, non sarà difficile prevedere quale forma presenteranno le protuberanze durante l'eclisse totale. Esisterebbe dunque un involucro comune, una atmosfera avvolgente le parti, che noi vediamo in pieno sole, la quale atmosfera non riuscirebbe a noi visibile, per debolezza di lume, che nelle sole circostanze di eclissi totali."[2]

At the Egyptian eclipse in 1882, Professor Tacchini devoted special attention to a repetition of these observations. On the three days preceding the eclipse drawings of the chromosphere and prominences were made in accordance with the system so long pursued by the same observer at Palermo and Rome, and just before totality another drawing was made with great care, and the height and width of base of the four principal prominences measured with a micrometer. During totality the same prominences were observed with the naked eye, and their dimensions determined with reference to the lunar diameter. The results are given in the following table, together with the heights of the same prominences measured by Professor Riccò at Palermo on the day of the eclipse:

Latitude of the Prominence	Height observed with the spectroscope		Height observed during the eclipse	Difference [Tacchini]	Base observed with the spectroscope	Base observed during the eclipse	Difference
	Tacchini Sohag	Riccò Palermo					
+18°	72″	75″	180″	108″	100″	180″	80″
+29	60	62	162	102	50	108	58
−15	48	47	180	132	100	231	131
−22	36	63	180	144	82	231	149

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[1] Taken for the most part from Professor Tacchini's work, *Eclissi totali di Sole del 1870, 1882, 1883, 1886 e 1887* (Roma: Tipografia Eredi Botta, 1888).

[2] *Loc. cit.*, p. 234.

In the hope of obtaining independent evidence regarding the dimensions of the prominences during totality, I have examined an excellent positive on glass made from one of the photographs taken at this eclipse. Unfortunately the lower parts of the prominences are so covered by the Moon's disk as to render measurement of the full height and width impossible, the time which had elapsed since the beginning of totality not being recorded on the photograph employed. The dimensions of the prominences seem, however, to exceed those found by Professor Tacchini before the eclipse. A most interesting fact is the presence on the photograph of a large number of small prominences not recorded in the spectroscopic observations of the chromosphere. It is well to bear in mind that these observations were made in the *Hα* line, and that the photographs taken during totality with the prismatic camera showed differences in the relative intensities of the prominence lines.[1] The reliability of Professor Tacchini's observations is further indicated by the appearance of the prominences during totality: "Le quattro protuberanze erano tinte in roseo chiaro, e molto più lucenti ai bordi e tanto che sembravano contornate da un filetto lucido bianco."[2] In view of Professor Tacchini's long experience as an observer of prominences, it may safely be said that these results should be considered to confirm those obtained at Terranova and may be accepted as establishing an important difference between the spectroscopic and eclipse images of prominences.

In 1883 Professor Tacchini observed the eclipse at Caroline Island and not only confirmed his earlier work, but discovered a new and remarkable variety of prominence: "Una cosa che mi sorprese e che aveva un aspetto singolare e per me nuovo, erano due getti o protuberanze bianche, la cui altezza non doveva essere minore di [illegible] del raggio lunare. Questi oggetti sembravano proprio come di argento filogranato, di una struttura cioè ed apparenza del tutto consimile a quella da me indicata per l'oggetto veduto al 1882 e che si definì per una cometa."[3] These "white" prominences were not visible in the spectroscope immediately after the eclipse. During totality the chromosphere was found to be much higher than in full sunlight observations.

At the Grenada eclipse in 1886 Professor Tacchini's discovery of white prominences was amply confirmed by the appearance during totality of a prominence from 10′ to 12′ high, independently seen by three observers and recorded on all the best photographs. To Professor Tacchini it appeared of a silver white color in its upper part, with a slight tinge of rose below.[1] Mr. Maunder described it as "of the intensest silver whiteness,"[2] while Professor Turner considered it to have a rosy tint throughout totality.[3] A searching spectroscopic examination of the chromosphere made immediately after totality failed to show any indication of this remarkable object, which was also invisible with the spectroscope at Rome and Palermo. Professor W. H. Pickering photographed the spectrum of this prominence, and found H and K without the hydrogen lines.[4] Captain Darwin found from an examination of the photographs taken with a prismatic camera that $H\beta$, $H\gamma$, $H\delta$, $H\zeta$ and *f* were probably also present, though they were extremely faint in comparison with the brilliant H and K lines.[5]

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[1] SCHUSTER and ABNEY, *Proc. R. Soc.* 35, 155, 1883.

[2] *Eclissi totali*, p. 16.

[3] *Ibid.*, p. 58.

Professor Tacchini found that of the nine prominences seen during totality but four were visible in full sunlight, apparently much reduced in both height and width of base. "Insistiamo intanto nel dire, che inquanto a cromosfera, ciò che vedesi tutto attorno al sole durante un'eclisse totale, non è paragonabile colla cromosfera veduta in pieno sole, perchè durante un'eclisse totale si vede uno strato roseo sfumato fino al bianco, al disopra del quale s'innalzano le grandi protuberanze, mentre i fiocchi lucenti e le piccole protuberanze che noi vediamo allo spettroscopio si confondono con quell' involucro stupendo, che deve venire formato dalla nebbia lucida più elevata ed involgente le piccole fiammelle, di cui vediamo costituita la cromosfera in pieno sole."[6]

These various observations have led Professor Tacchini to the following classification of solar prominences:

"1. Protuberanze visibili in pieno sole e durante l'eclisse totale, ma ben più alte, larghe e compatte, senza cioè il frastagliamento che si osserva quasi sempre nello spettroscopio a sole non eclissato.

2. Protuberanze visibili in pieno sole e durante la totalità, con poco differenza nella forma.

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[1] *Ibid*, p. 187.

[2] *Phil. Trans.*, 180, 345, 1889.

[3] *Phil. Trans.*, 180, 392, 1889.

[4] *Annals of Harvard College Observatory*, 18, 99.

[5] *Phil. Trans.*, 180, 320, 1889.

[6] *Loc. cit.*, p. 197.

3. Protuberanze visibili durante l'eclisse totale e non visibili in pieno sole.

4. Cromosfera solare sempre più compatta ed alta durante un'eclisse totale, in confronto di quanto ci mostra lo spettroscopio a sole libero."[1]

Let us now consider the observations made at the eclipse of 1893, April 16. Plate XXVI., which is reproduced from a drawing made by my assistant, Mr. Ellerman, brings together the visual and photographic results obtained by four observers. Fig. 1 (the outer circle) represents the prominences photographed by Professor Schaeberle at Mina Bronces, Chile, with a photoheliograph of 40 feet focal length. The drawing was made from a series of beautiful positives on glass from the original negatives, presented by the Lick Observatory to the Yerkes Observatory. While it fails to show all that could be seen on the original negatives, it is perhaps sufficiently complete for our present purpose. On account of the overlying image of the Moon, the forms of the lower parts of some of the prominences are very uncertain. For this reason no attempt was made to indicate the base of the prominence at P. A. 294°. Fig. 2 (from a plate in *A. N.* 3166) represents the prominences as drawn by Herr Fényi at Kalocsa, Hungary, at the time of totality in Chile. The observations were made in the $H\alpha$ line with a Hilger 6-prism automatic spectroscope attached to a 7-inch refractor. All of the prominences (excepting one at P. A. 30°, which showed some motion in the line of sight) were of the quiescent type, and changed but very little in form or position during the day. The weather at Kalocsa was particularly favorable.[2] Fig. 3 was drawn from two negatives of the prominences made in the K line with the spectroheliograph attached to the 12-inch telescope of the Kenwood Observatory.[3] It was cloudy here at the time of totality in Chile, and no photographs could be made until about two hours later, when the thick haze which still covered the Sun made satisfactory observations impossible. Considering the circumstances in which they were made, it is not surprising that the photographs are decidedly inferior to those ordinarily obtained here. Fig. 4 shows the two large prominences at P. A. 180° and P. A. 294° as photographed by Mr. A. Fowler during totality at Fundium, Africa. The instrument used was a prismatic camera of 6 inches aperture with a prism of 45° angle. The drawing was copied from the K image on a beautiful glass positive, one of a series of photographs of this

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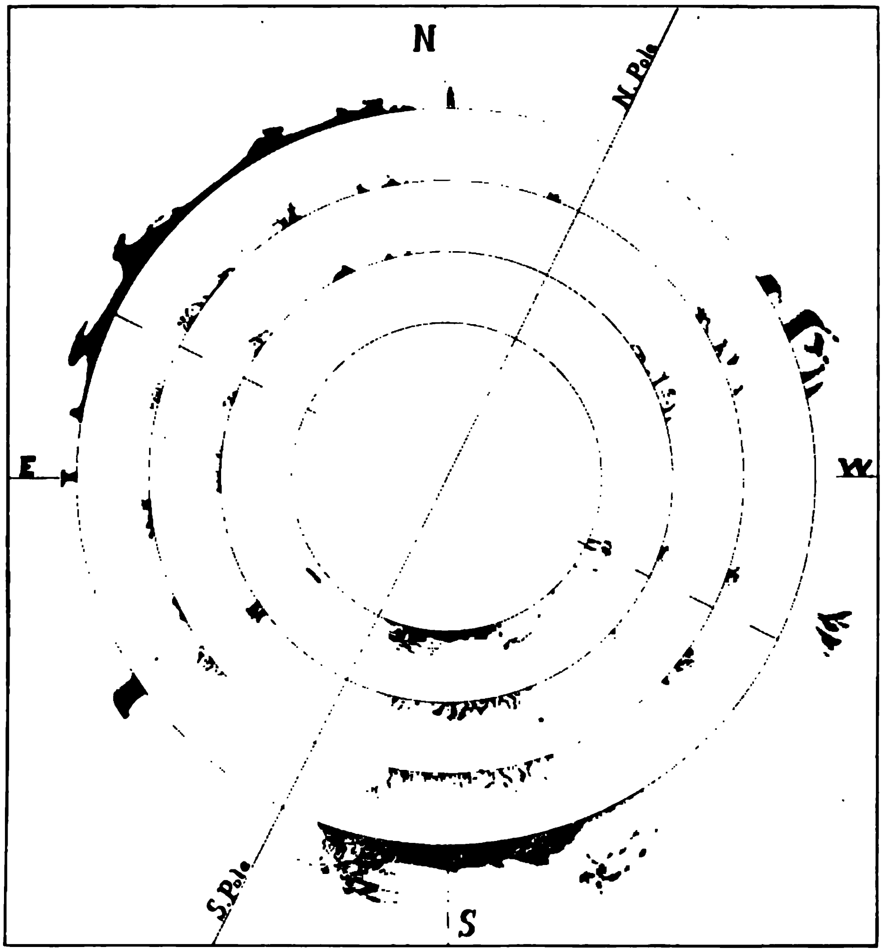
[1] *Loc. cit.*, p. 236.

[2] *A. N.* 3166, p. 365, 1893.

[3] *A. and A.* 12, 450, 1893.

PLATE XXVI.



PROMINENCES OF 1893, APRIL 16:

(1) **Photographed during total eclipse by Professor J. M. Schaeberle at Mina Bronces, Chile (outer circle).**
(2) **Observed visually in full sunlight by Herr J. Fényi at Kalocsa, Hungary.**
(3) **Photographed in full sunlight by Professor George E. Hale at Chicago, U. S. A.**
(4) **Photographed during total eclipse by Mr. A. Fowler at Fundium, Africa (many prominences not shown in the drawing).**

eclipse which I owe to the kindness of Mr. Fowler. As some of the prominences are hidden on this positive by the Moon's disk, it has been thought sufficient to reproduce only those shown in Fig. 4.

The following table gives the approximate position angles and heights of the prominences recorded by Professor Schaeberle, Herr Fényi and myself. The lack of agreement of the position angles in many cases seems to be due in part to the different methods of designating the prominences adopted by the several observers.

Schaeberle		Fényi		Hale	
P. A.	Height	P. A.	Height	P. A.	Height
4°	0'.8	....	....	....	....
7°	0'.8	....	....	....	....
9°	0'.8	10°	(small)	9° to 10°.5	0'.3
11°	1'.0	....	....	....	....
17°	1'.0	....	....	14° to 16	0'.5
18° to 27°	0'.5 to 0'.2	....	....	24° to 29°	0'.7
30° to 58°	1'.0 at 30° 1'.3 at 58°	28°30' to 33° 24'; 53° 16' to 60°6'	44" 51"	51° to 56°	1'.0
59° to 69°	0'.7	....	....	....	....
69° to 77°	1'.0	73°34' to 75° 48'	33	68° to 74°	0'.7
77° to 83°	(seven small prominences)	....	....	....	....
87° to 96°	1'.1	94° to 101°	(small)	86° to 99°	0'.4
125° to 130°	1'.5	124° 32' to 130°50'	54"	124° to 127°	1'.0
165° to 215°	3'.2 at 168° 1'.0 at 192° 1'.5 at 197° 3'.8 at 202°	169° 30' to 201°4'	128" at 168° 301" at 201° 4'	165° to 210°	2'.7 at 168° 2'.5 at 205°
....	....	226°	(small)	....	....
....	....	229° 22' to 233°48'	34"	226° to 228°	0'.7
250°	3'.0	251°	(small)	248° to 252°	0'.5
284°	1'.0	....	....	284°.5	0'.7
286° to 289°	1'.6	286° 30' to 287°8'	41"	286° to 287°	1'.2
289° to 291°.5	1'.8	292°	59"	289° 291°.5	0'.3 0'.3
289° to 294°	2'.8	....	....	....	....
294°	2'.2	294° 26' to 295°24'	54"	293°.5 to 295°	1'.4
300° to 302°	0'.8	303° to 304°	29"	300° to 306°	0'.5
....	....	339°	(small)	....	....
359°	1'.0	....	....	....	....

In comparing together these results the following summary of data relating to them will be of service:

SCHAEBERLE.—Eclipsed Sun. Clear sky. Large image. Superposition on photographic plate of images due to hydrogen, calcium and other substances, some of them necessarily not in perfect focus. Plate sensitive only in more refrangible part of spectrum: red, yellow and green images consequently lost or greatly underexposed. Base of many prominences covered by Moon.

FÉNYI.—Full sunlight. Clear sky. Small image, magnified by eyepiece of spectroscope. *Hα* line used, hence the prominence forms are those given by the red hydrogen line, which produced no effect upon the plates of the other observers. Necessary imperfections of hasty drawings, affected by insensitiveness of observer's eye to small contrasts. Time: about that of totality at Mina Bronces.

HALE.—Full sunlight. Very white sky. Small image, photographed by spectroheliograph without enlargement. K line used, giving distribution of calcium in prominences. Spectroheliograph of old type, in which image is distorted, making measurement of heights and position angles somewhat uncertain; motion of slits unsatisfactory, so that K line did not remain on the second slit during the entire time of one of the exposures. Time: about two hours after totality at Mina Bronces.

FOWLER.—Eclipsed Sun. Sky slightly hazy. Small image, photographed at focus of prismatic camera. Chromosphere and prominence images corresponding to a large number of lines shown on photographs, but only a portion of that corresponding to K reproduced here. Time: about two hours after totality at Mina Bronces.

A comparison of the hydrogen and other images with the calcium (K) image on Mr. Fowler's plates shows that the latter is the largest and brightest in the case of all the prominences. This was also found to be true at the eclipse of 1882, and might have been predicted from our knowledge of the relative length and brightness of the lines in the spectrum of the prominences. In Mr. Fowler's photographs the upper part of the prominence at P.A. 210° is shown in the *Hζ* line, though its images in the less refrangible hydrogen lines seem to have been hardly bright enough to affect the plate. It is faintly shown on my own plates, but was not seen by Herr Fényi in the *Hα* line. Quite apart from the question of brightness, however, it has been found at the Kenwood Observatory that the forms of prominences in the hydrogen and calcium lines are in some cases distinctly different. Hence Herr Fényi's results should differ to a certain extent from the others, and, in general, the prominence forms observed visually should be somewhat smaller than the calcium images photographed with the spectroheliograph, or the composite forms photographed during a total eclipse. This failure of the ordinary visual method to render the true prominence forms visible in their full extent in sunlight must be regarded as having already been established by Professor Tacchini.

It is clear that on account of the greater size and brightness of the K image, photographs taken with the spectroheliograph should resemble eclipse photographs more closely than $H\alpha$ images do. It remains to be determined in what degree the results obtained with this instrument fall short of those obtained during total eclipses. Had the sky been clear in Chicago at the time of the eclipse it might have been possible to give a definite answer to this question. The fact that the prominences photographed by Professor Schaeberle considerably exceed in height those shown on my negatives is doubtless partly due to the difference in the atmospheric conditions and in the size of the image photographed. It is probable, however, that with apparatus such as that used by Professor Schaeberle during this eclipse, his conclusion is justified that faint details can be photographed which cannot be observed either visually or photographically in full sunlight. But before this can be considered definitely established it will be necessary to compare with eclipse results photographs taken simultaneously with a telescope of equal focal length and a spectroheliograph of the most approved type, under good atmospheric conditions.

In a paper published in 1891, I showed that the photographic method of recording the forms of prominences in the H and K lines, which was then giving its first results, would in all probability render possible the study of the "white" prominences in full sunlight. After pointing out the many advantages to be expected from the use of these lines in photographic observations of the prominences, I cited the fact that H and K, without the less refrangible hydrogen lines, were present in the spectrum of the great "white" prominence of the 1886 eclipse, in support of the conclusion that such prominences should be shown on spectroheliograms.[1] Since that time I have devoted some attention to a comparison of visual ($H\alpha$) and photographic (K) observations, but

[1] "Photography and the Invisible Solar Prominences," *Sidereal Messenger*, 10, 262, 1891.

I have not had an opportunity to investigate the matter thoroughly. I now wish to suggest that the prominence at P.A. 210°, which was photographed in South America, Africa and Chicago, but was not seen at Kalocsa in the *Hα* line, may have been an object of this class. I have found from an examination of Mr. Fowler's objective prism plates that, although the H and K lines were bright in this prominence, the hydrogen lines were so feeble as to make only the slightest impression on the plate. In some of the other prominences the hydrogen lines were nearly as strong as H and K, thus confirming the discovery of the different relative intensities of these lines made by Abney and Schuster at the Egyptian eclipse in 1883. Thus, in spite of the unfavorable atmospheric conditions which prevailed at Chicago, this prominence was photographed in the K line, while under the best of conditions it was invisible at Kalocsa in *Hα*.

Whether or not this prominence appeared white to the naked eye during totality, the published reports of this eclipse do not seem to say. It should be stated, however, that Mr. Fowler's plates apparently offer no evidence that this prominence was characterized by a continuous spectrum. But I venture to doubt whether a "white" prominence necessarily has a continuous spectrum. It is true that the striking object of this class observed at Grenada in 1886 had, according to Professor W. H. Pickering, "a brilliant continuous spectrum in the visible region,"[1] but I do not know that any confirmation of this result was obtained by the other observers. If it is true that H and K are the only intense bright lines in the spectra of the "white" prominences, it is perhaps unnecessary to seek further in order to discover the cause of the "white" color of these objects. Light of this wave-length, when observed in the spectrum of the electric arc, all other light being excluded from the eye, is of a distinctly violet color. Even the carbon flutings beginning at λ 3890 appear violet to the eye. But when the H and K lines are bright enough to be seen in the spectrum of a prominence, as is not infrequently the case, their violet color is so far diminished as to be hardly noticeable, and they appear distinctly white. I can account for this apparent difference only by supposing that the violet color is far less appreciable when the eye is exposed to the bright spectrum of the sky, as is the case when a prominence is under observation. The conditions existing during the total phase of a solar eclipse are very similar, for while observing the prominences the eye is exposed to the bright light of the corona. The light of the "white" prominences is also compared by the observer with the light of the corona and with the brilliant pink or red light of the ordinary prominences. As a result the violet color which must characterize all prominences in which the H and K lines predominate seems to escape attention. This may perhaps be due to a considerable admixture of white light radiated from or reflected by particles distributed throughout the mass of the prominence. I have occasionally found that eruptive prominences give a continuous spectrum,[1] but quiescent ones apparently do not, if we may judge from the fact that the spectrum of the sky is not materially brightened over such prominences. It is probably impossible to say at present whether the "white" prominences belong to the eruptive class, or to draw any *a priori* conclusions regarding the character of their spectra. It is to be hoped that special attention will be directed to this point at the coming eclipse.[2]

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[1] *Annals of Harvard College Observatory*, **18**, 99.

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[1] *A. and A.* 11, 813, 1892.

[2] An examination of the literature of total solar eclipses will show that the depth of color of the prominences undoubtedly varies considerably. After due allowance has been made for personal equation, there seems good reason to believe that their color, which is ordinarily described as pink or rose, is sometimes deep ruby red and less frequently nearly white. Without attempting an exhaustive study of the literature with reference to this point, I have thought it worth while to append certain observations which are of interest in the present connection, though the scientific value of many of them is evidently doubtful.

In his *History of Astronomy* Grant quotes the following observations of the color of the prominences at the eclipse of 1842: Baily, red, tinged with lilac or purple; Biela, dark reddish color, approaching purple; Littrow, red, with a tinge of blue . . . . "their aspect, which was first white, changed to rose color and then to violet, and afterwards passed in a reverse order through the same tints. . . . The protuberances were visible *before they assumed a coloured hue*, and they continued to be visible after their colour was dissipated;" Valz, white, like the Sun. In 1868 Hennessy saw a prominence which differed in color from the others: "Its left edge was a bright blue, like a brilliant sapphire with light thrown upon it; next to that was the so-called rose-colour, and, at the right corner, a sparkling ruby tint" (*Proc. R. Soc.* 17, 86, 1868).

In his report on the eclipse of January 1, 1889 (*Reports on the Observations of the Total Eclipse of the Sun of January 1, 1889*, published by the Lick Observatory, p. 204) Dr. Swift quotes the following observations of prominence colors made at the eclipse of 1869: Alexander, white, later portions were tinted pale rose; Halstead, red, afterwards white; Hines, white, later brilliant rose; Browne, white, bordered with delicate rose; Zentmayer, white, tinged with blue; Moelling, white; Cutts, white; Schott, two prominences white, others delicate pink; Swift, bright red. In 1889 Kinne saw "a small, reddish purple Sun-flame near the north pole of the Sun"; Irish saw a

It has seemed to me worth while to point out, in the absence of more complete knowledge, that all of Professor Tacchini's classes of prominences can be accounted for with some degree of probability by the well-established fact of a considerable variation in the relative intensities of the hydrogen and calcium lines. His first class includes prominences which are visible in full sunlight and during a total eclipse, but in the latter case are much higher, broader and more compact, without the structure ordinarily observed with a spectroscope and an uneclipsed Sun. The photographs seem to show that the structure exists, though in a naked eye view during totality it might easily be overlooked. In attempting to explain the difference here noted let us remember (1) that such prominences were seen by Professor Tacchini to be bordered by a "white" fringe; (2) that H and K frequently seem to extend to a greater height than that attained by the $H\alpha$ line in prominences, and that consequently the prominence image is often larger in K than in $H\alpha$; (3) that the spectroscopic images of many prominences do not end abruptly at a certain height above the limb, but disappear at a point where the ratio of their brightness to that of the spectrum of the sky does not exceed a certain quantity, which probably lies between $\frac{1}{80}$ and $\frac{1}{50}$. The reduction in the brightness of the sky during totality is probably great enough of itself to render visible faint parts of prominences that are invisible in $H\alpha$ in full sunlight. The prominences must thus appear larger than they do in the spectroscope, and as the calcium extends further than the hydrogen, the pink image (which takes its color from the great visual intensity of the $H\alpha$ light) must be bordered with violet, which, as I have already indicated, would not improbably appear white.

The second class comprises prominences visible in full sunlight and during totality, with little difference in form. These are probably bright prominences, which terminate abruptly or decrease very rapidly

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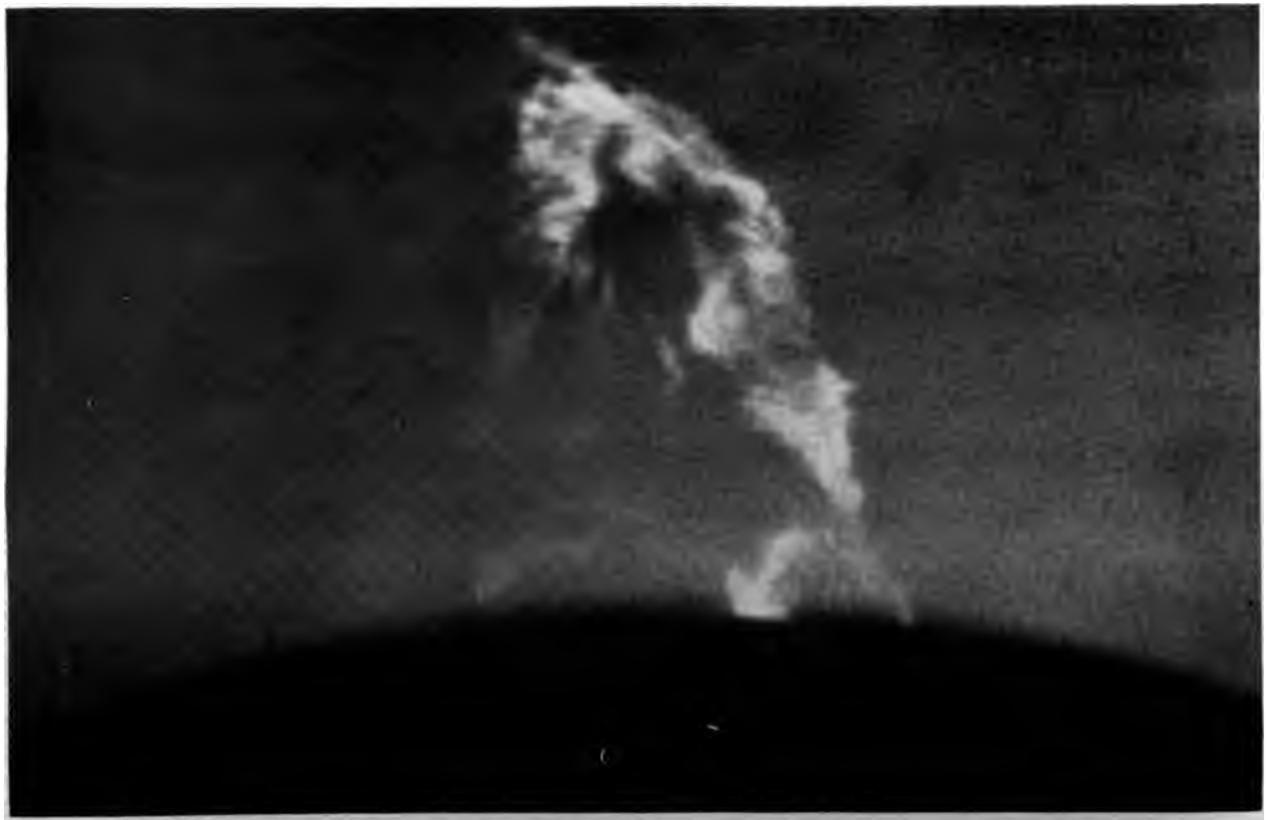
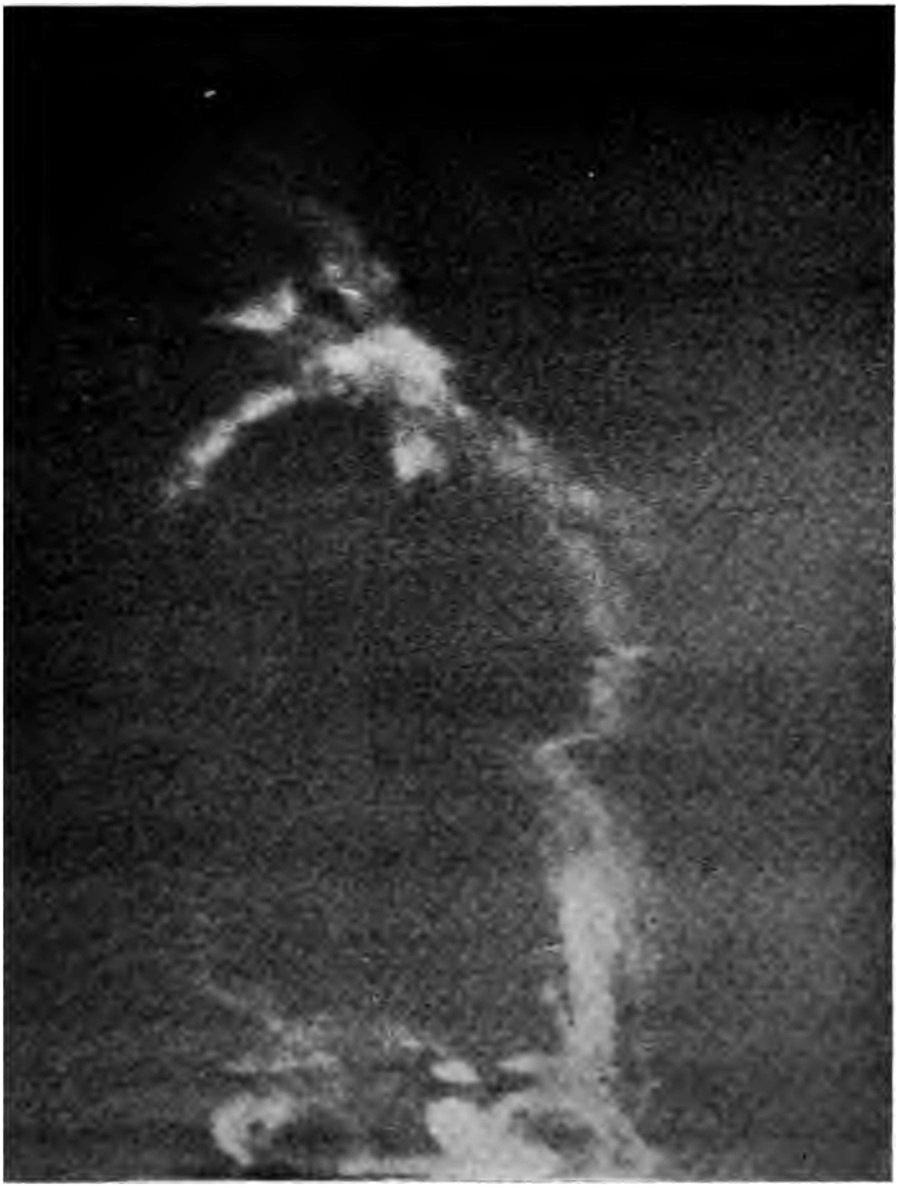
cone-shaped prominence, having "a hue of ashes of roses"; Swift was much surprised to find the prominences "as white as burnished silver" (*Lick Observatory Report*, pp. 155, 193 and 203). Among the conclusions drawn by Secchi from his observations of the eclipse of 1860 is the following: "Les protubérances sont des amas de matière lumineuse ayant une grande vivacité et possédant une activité photogéniqué très-remarquable. Cette activité est si grande, que plusieurs des protubérances que nous voyons sur nos épreuves, et précisément la protubérance *E* (figured in *Le Soleil*), n' ont pu être observées directement, même avec de bons instruments: c'est peut-être parce qu'elles n'émettaient que des rayons chimiques et peu ou point de rayons lumineux." (*Le Soleil* I, p. 385).

PLATE XXVII.



ERUPTIVE PROMINENCE PHOTOGRAPHED AT THE KENWOOD OBSERVATORY
1895, MARCH 24, 22^h 40^m CHICAGO M. T.

PLATE XXVIII.



RUPTIVE PROMINENCE PHOTOGRAPHED AT THE KENWOOD OBSERVATORY 1895, MARCH 24, 22^h 58^m CHICAGO M. T.

in brightness at a certain distance from the limb, and give very bright hydrogen lines.

The third class comprises prominences visible during a total eclipse, but not visible with a spectroscope (using *Hα*) in full sunlight, *i. e.*, the "white" prominences. These seem to be prominences of moderate brightness, in which the hydrogen lines (particularly *Hα*) are very faint in comparison with H and K; they may perhaps also have a continuous spectrum. It is probable that they can be photographed in full sunlight with a spectroheliograph.

Finally, the chromosphere may have a "white" border and appear higher during totality, for the reasons given in the case of the first class of prominences.

It should be added that these suggestions are made only hypothetically, in the hope that they may be of some service in clearing up a long standing problem.[1] The rather full statement of Professor Tacchini's observations, which I have thought it well to give on account of the slight recognition this important work has received from many writers on solar phenomena, may perhaps serve to direct renewed attention to the prominences on the occasion of the coming eclipse.

As the prominences photographed at the Kenwood Observatory 1893, April 16, are not suitable for reproduction, I have thought it well to select from our collection three photographs (Plates XXIII., XXVII., and XXVIII.) for comparison with the largest prominence shown on the Mina Bronces negatives; this is the object at P. A. 210°, which may perhaps be a "white" prominence. Professor Schaeberle has been kind enough to prepare a special enlargement (Plate XXV.) for the present purpose, which brings out as many of the details of the original plate as can readily be shown in this rather unsatisfactory way. It may be said of all the plates that the beauty of the positives on glass from which they were made is for the most part lost. Contrasts that were before scarcely noticeable are now harsh and offensive, detail and definition is lost, and nothing is gained to offset these losses. In some cases the grain of the plate is especially conspicuous; this is particularly true of the great eruptive prominence from the Kenwood collection. To explain this it may be mentioned that our photographs were taken with a 50$^{\text{mm}}$ focal image of the Sun, while the image photographed by Professor Schaeberle was 112$^{\text{mm}}$ in diameter. In order to reproduce all the plates on the same scale, it was therefore necessary to enlarge the Kenwood negatives more than twice as much as Professor Schaeberle's. As the scale of the reproductions is about 16.2 inches to the solar diameter, an eightfold enlargement was required for our plates; this was sufficient to bring out the granulation together with the chance defects of the originals in a disagreeable manner. The sharpness of the photographs must be judged from the image of the prominence itself, and not from the outline of the metal disk which covers the Sun. The latter was necessarily out of focus, as it was considerably above the plane of the spectroheliograph slit, and separated from it by a plate of blue glass.

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[1] Former explanations of the "white" prominences include Lockyer's conclusion that they are descending masses of cooled vapor (*Eclissi totali*, p. 189) and the following from Proctor's *Old and New Astronomy*, p. 401: "This discovery (Tacchini's) seems only explicable by my theory that the ruddy, jet-like portion of the prominence owes its light, and therefore its heat, to the velocity of outrush with which ejected matter passes through the hydrogen and helium already outside the Sun, and not to the outrush of those gases themselves in an intensely heated condition. For outrushing gases brought from a region of great pressure to a region of very small pressure would expand rapidly and be quickly cooled, so that the outlines of the heated and luminous portion would be sharply defined, and they would be surrounded by a region not only cooler than the ejected matter, but even cooler than the surrounding atmosphere. On the other hand, ejected matter would travel outwards with diminishing velocity owing to the retarding action of solar gravity, while such portions as return after reaching a certain height would not only be scattered around somewhat widely, but would reach the Sun's surface with less velocity than they had at leaving it, because of the effects of frictional resistance. Hence, above and around the region of rapid outrush, intense heat, and brilliant light, there would be a region where the hydrogen and helium in the Sun's atmosphere would be heated by the rush of matter through it, and would therefore be luminous, but would be less heated than the region of outrush. This exactly corresponds with what Tacchini has discovered."

With these circumstances in mind the eclipse photograph by Professor Schaeberle, which may fairly be considered as one of the best of its kind, may be compared with the spectroheliograms. I think it will be seen that in sharpness of definition, and *apparently* in the rendering of faint details, the latter do not fall far behind. These are not shown as *average* results. They represent some of the best results obtained at the Kenwood Observatory. They serve, however, to give some idea of what can be photographed with apparatus which is open to very decided improvement. Were eclipse results obtained on the same dates available for comparison, such photographs would do much to assist in determining the exact nature of the apparent changes in prominence forms brought about by the reduction in brightness of the glare around the Sun.

I had intended to conclude this paper with some discussion of Professor Schaeberle's theory that prominences are made up of numberless interlacing streams of elliptical form, but the space which it has seemed necessary to give to the "white" prominences has already carried it beyond desirable limits, and further considerations must be deferred for the present.

GEORGE E. HALE.

KENWOOD OBSERVATORY,
April 11, 1896.

ON A NEW METHOD OF PREPARING PLATES SENSITIVE TO THE ULTRA-VIOLET RAYS.[1]

I.—PRELIMINARY PREPARATION OF THE PLATE FOR COATING WITH SILVER BROMIDE.

IF plates prepared as above are treated with hypo, the greater part of the developed picture flows away as soon as the remainder of the yellow ground of the plate forming the unexposed parts disappears. This defect may be prevented by:

(*a*) Preparing the silver bromide film very thin.

(*b*) Coating the glass plate with some binding material before depositing the silver bromide.

(*c*) Mixing the bromide itself with a binding material.

(a) With a thick film the developed picture rests upon a layer of unaltered silver bromide, and by the fixing this is replaced by an equally thick layer of fluid which causes the picture to be suspended close over the glass. If the tray is moved, the film forming the picture is broken up and floats off. With a thin coating the greater part of the image is reduced all through the film. The fixing solution then acts more on the sides of the reduced silver than underneath it, so that the undermined parts of the film remain fast to the glass along with the other parts and are prevented from being washed away. But the use of silver bromide without a binding material is not to be recommended. Even with a proper thickness of film, the plates require the greatest care after fixing.

In cases when the employment of a binding material is not permissible (as when it is desired to ascertain the behavior of the spectrum with pure silver haloid), it is better not to fix at all. In darkness the plates can be preserved unchanged in color for a long time. If the plate must under any circumstances be fixed, then it is better to employ a gelatine bath first. This also gives the finished plate more resistance. The fixed image from a thin film of pure silver haloid on plain glass has no strength, and is very sensitive to mechanical pressure.

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[1] Continued from page 226.

(b) If the glass plate to be sensitized is first coated with gelatine, then even a thick film of pure silver bromide holds so strongly that the fixing with hypo does it no injury.

For this substratum I use a warm 2 per cent. solution of gelatine which is liberally poured onto the carefully cleaned and warmed plate and allowed to flow over it and run off at one corner. The plate is then stood up to dry in a place free from dust on blotting paper, with the prepared side inwards, and coated soon afterwards with the silver bromide.

The coating of silver bromide is very sensitive to irregularities in the gelatine coating; particles of dust, burst air bubbles and inequalities in the coating spoil the deposition of the silver bromide and give rise to a number of defects in the plates, which in most cases do not appear till the development. The coating with gelatine must therefore be done with the greatest care. Above all, air bubbles must be avoided. Even the smallest bubbles burst, and where they are the surface of the glass is exposed, and this, in certain cases which will be referred to later, in consequence of the insensitiveness of the silver bromide deposited upon it, becomes uncovered on the developed plate all around them.

The gelatine coating should be as thin as possible. The thinner it is, so much the less will the almost unavoidable differences in its thickness affect the silver bromide film; the stronger the image sticks to the glass, the less stained the gelatine becomes in the developer. Another advantage to be noted, especially with very small plates, is that as the plates must be cut from the prepared side, the cutting can be done much more neatly and exactly through the film in proportion as the gelatine is thinner. (The plates cannot be cut from the back on account of the fragility of the bromide film.)

(c) If the bromide of silver is itself mixed with a binding material, then the substratum of gelatine is unnecessary. This can be done in a suitable way by precipitating the silver bromide from solutions containing gelatine. In this case the particles of bromide, as is well known, contain gelatine and, as I observed at the outset, hold very firmly when applied on glass and dried.

The proportion of gelatine in my silver bromide solution varied between 1:18,000 and 1:1550. Its influence on the sensitiveness of the plates will be considered later.

It should, however, be mentioned at once, that for reasons which will be explained hereafter, I now use the gelatine substratum for all plates, even when the silver bromide contains gelatine.

II. PREPARATION OF THE SILVER BROMIDE.

(*a*) *Without gelatine.*—To prepare silver bromide as a fine gradually deposited precipitate, requires very greatly diluted solutions and a large excess of potassium bromide. I dissolve 2.8 grams of potassium bromide in 4 liters of distilled water, and 2.0 grams of silver nitrate in 100^{cc} of distilled water, and in the light of the dark-room pour the silver solution in small quantities into the bromide solution, constantly stirring the while. The liquid so obtained is tolerably translucent and colored red by transmitted light, and after filtering is ready for the precipitation of the silver bromide. In this case I do not use the whole of the silver bromide, but content myself with what falls in one or two days. To wait till the fluid over the plate is quite clear would take weeks.

The liquid with the precipitate becomes visibly denser as soon as ammonia is added. The bromide also settles much quicker than before, and ten to twelve hours will be sufficient. For this purpose I add 30^{cc} of ammonia to the above solution.

(*b*) *With gelatine.*—To the solution of potassium bromide given above I add 0.2 gram of hard emulsion gelatine, dissolved by heat, and otherwise proceed as before. Ammonia also acts beneficially on the formation and settlement of the silver bromide precipitate.

All these methods yield a silver bromide which is only slightly sensitive even when prepared with warm solutions. Greater sensitiveness was obtained by prolonged heating of the suspended silver bromide. The greatly diluted solutions are not well adapted for this and better results can be obtained with an emulsion weak in gelatine. If this is dissolved in proper quantity in hot water, the silver bromide precipitates gradually. It also contains gelatine, but gives a more sensitive coating than bromide which is deposited from very dilute solutions.

The emulsion I use for this is composed as follows:

A		*B*	
Potassium bromide	12 grams.	Silver nitrate	15 grams
Emulsion gelatine	2 "	Distilled water	200^{cc}
Distilled water	200^{cc}		

A is dissolved with heat, and *B*, also warmed, is poured in very gradually in small quantities in the light of the dark-room. During the mixing *A* must be kept well stirred.

The unripened emulsion can be used at once for precipitating, but the plates are then scarcely more sensitive than in the former method. Greater sensitiveness must be obtained by warming or boiling the emulsion, adding ammonia or other means usually employed with sensitive gelatine emulsions as laid down in the text-books. The only precaution to be taken during the ripening is to keep the emulsion well shaken, as, owing to the small quantity of gelatine, a good deal of the bromide will settle to the bottom. 100^{cc} of this emulsion dissolved in 4 liters of water, shaken up and filtered several times, gives a good precipitating fluid. It is well to allow the solution to stand a few hours before use, in order to allow the heavier particles of dust and other impurities which may go through the filter to settle, so that at least the heaviest of them may be kept off the plate. By this precaution, the formation of a number of small defects on the plate, even if they may be almost microscopic, is avoided.

The silver bromide can also be obtained from ordinary gelatine dry plates, though the emulsions are of different degrees of richness in gelatine. The emulsion is dissolved in a suitable quantity of hot water, and the further procedure is as before. These plates also have great sensitiveness for the ultra-violet rays. My observations with them, however, have not extended beyond $\lambda 1700$. But I have no doubt that these plates would be useful beyond that point.

The employment of ordinary dry plates can only be considered when it is desired to prepare plates sensitive to the ultra-violet with the least expenditure of time, trouble and cost. When it is a matter of only a few experiments, or perhaps it is merely desired to ascertain the behavior of the new plates, it is better to take the silver bromide from the coating of commercial plates. For this purpose a plate of this kind is cut into slips 1^{cm} or 2^{cm} wide, which are placed in a flask full of hot water (0.5 to 0.6 liter for a plate $13^{cm} \times 18^{cm}$) and well shaken. As soon as the coating of emulsion has dissolved, the contents of the flask are filtered, allowed to stand quietly for about an hour, and then poured into the precipitating dish, in which a second dry plate has been laid with the coated side upwards.

III.—INCREASING THE SENSITIVENESS OF SILVER BROMIDE TO THE ULTRA-VIOLET RAYS.

The sensitiveness of silver bromide to the rays beyond $\lambda 2200$ may be increased by the addition of silver iodide. In the same way as gelatine emulsion plates with bromide of silver are improved by iodide, so may also be the plates sensitive to the ultra-violet. Plates have been tried containing 5, 10 and 20 per cent. of silver iodide, and better results have throughout been obtained than with pure silver bromide.

The iodide increases not only the sensitiveness but also the intensity and clearness. *This only obtains, however, when both the bromide and the iodide are precipitated together from the same solution.* A mixture of the two precipitated apart from one another gives plates of very ordinary sensitiveness. Pure silver bromo-iodide is consequently also very variably sensitive to the rays beyond $\lambda 2200$, according to the manner of its preparation, as bromo-iodide emulsions with gelatine are with respect to the rest of the spectrum.[1]

I give below the formula for preparing bromo-iodized plates sensitive to the ultra-violet, which have answered better than all others for my photographs of the shortest wave-lengths:

A		*B*	
Potassium bromide	6 grams	Silver nitrate	8.1 grams
" iodide	0.6 "	Distilled water	100^{cc}
Emulsion gelatine	1 "		
Distilled water	100^{cc}		

After melting the swollen gelatine, both solutions being heated to 50° or 60° C., *B* is poured in very small quantities into *A* in the dark room, being well and often stirred meanwhile, set in boiling water for half an hour and also well stirred, then allowed to cool 40° C., 4^{cc} ammonia added and again well stirred up, allowed to cool further for half an hour or warmed in a water bath at not over 40° C. After that 64^{cc} of the fluid is poured into 4 liters of warm water at not over 40° C., well stirred, filtered, and after standing for 1 to 2 hours, the silver bromo-iodide is left to settle as described before. After drying, the plates must be washed for a time in standing or quietly flowing water, which at first is frequently changed.

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[1] I have obtained better results with plates containing about 10 parts of silver iodide to 100 parts of silver bromide, than with any other plates. For photographing the most refrangible rays of the new spectral region I have used only bromo-iodide plates. It should, however, be mentioned that a year elapsed between the preparation and the exposure, during which time the specially high sensitiveness may have been acquired by an after ripening.

IV. THE SETTLING OF THE SILVER BROMIDE.

Glass developing trays with flat bottoms made of moulded glass are suitable for settling the silver bromide. The inside dimensions of the bottom should be at least five-eighths of an inch larger than the plate. After a good cleaning with sulphuric acid, the dish is filled to about three-fourths of its depth with the filtered bromide solution, and the plate, dusted on both sides with a soft brush, is laid down so that it is at least two-fifths of an inch from the farthest edge. The time required for settling varies according to the preparation of the silver bromide. As soon as the edges of the plate can be seen through the fluid it is time to empty the dish and dry the plate. The dish is inclined forward and the fluid runs off with a syphon reaching to the bottom of the dish in front of the plate. The remaining solution is soaked up carefully with blotting paper from one corner so as not to damage the surface of the plate. The plate can then be taken out of the dish. Care must be taken not to touch the film with the fingers. If the film contains gelatine, it will contract for some distance around the finger mark and probably damage the coating. The plates should be taken out of the dish by the edge and held by the lower side and be kept as nearly as possible horizontal. Then they are laid to dry in a place free from dust, but not in a drying box as for gelatine emulsion plates. A few hours are sufficient. The plates dry more quickly standing, only the film is easily split by so doing and shifts away in places; or the heavier particles may move downward and cause furrows which will develop as transparent lines with denser edges.

V.—THE DRY PLATES.

(*a*) *Before exposure.*—In drying, the sensitive coating of the plates will be distinctly more transparent for the visible light rays, especially if the silver bromide contains gelatine. I have had plates which while wet were only translucent, but after drying were completely transparent to my dark room light (stearine candle light filtered through three thicknesses of brown tissue paper).

After drying, silver bromide containing gelatine adheres very strongly to the plate; pure silver bromide on a gelatine coating is not so good, especially with a thick coating, and on a plain glass surface makes such a loose deposit that its employment for photographic negatives is attended with great difficulties. However, when once they are dry these plates can be set up standing in water to remove the potash salts in the coating, which is as necessary in this as in the other preparations.

The coating is very sensitive to mechanical pressure. It will scarcely even bear dusting with a brush without injury. To direct pressure it is generally less sensitive. When cutting with a diamond, the rule may be laid direct on the sensitive side without fear of injury to the film. Under still stronger pressure many sensitive coatings change their properties. I came to this conclusion from the fact that plate numbers stamped on with a soft rubber stamp always develop intensely black, whereas the same method of marking in all other cases gives the numbers as clear as glass.

The color of the coating of the plates is, with silver bromide, white, with a trace of yellow; with a mixture of silver bromide 100 and silver iodide 5, somewhat yellower; with the bromide and iodide in the same proportions, precipitated together from the same solution, citron yellow, and with 10 parts of iodide, light orange yellow.

Pure silver haloid gives a dull coating; with gelatine it is more glossy. By the light of the dark room it generally appears faultless, except at the edges, which show uneven streaks. By daylight, however, it is different, and fogginess and unevenness of the deposit may often be noticed. On development, these appear as dense spots unless certain precautions are very carefully observed. Moreover, the film always contains some particles of dust, however carefully the plates may be prepared, and under the miscroscope these spoil the image and sometimes render it useless. Fortunately this only happens when the image of a line taken with a very fine and short slit opening falls upon impurities, and so becomes uncertain.

(*b*) *The photo-chemical coloring.*—My observations will here be confined to films containing gelatine, and even with these only to a few tried in direct sunlight. In presence of sunlight, the sensitive films are affected differently according to their composition.

Silver bromide is colored at first greenish blue, and becomes gray blue without gaining greater intensity. If only part of the plate is exposed, this appears surrounded by a greenish blue aureola, the result of total reflection, by which the rays are thrown off from the back of the plate. A mixture of iodide and bromide darkens much more strongly than pure silver bromide. It becomes gray blue and shows only a trifling halo. The iodide and bromide precipitated together takes a still more intense gray blue color and shows almost no aureola.

(*c*) *The photographic coloring.*—The color acquired in development by plates sensitive to the ultra-violet is, as is universal in photography, quite different from the photo-chemical coloring. For development only pyro and soda are used. With normal exposure, the film of silver bromide is colored gray black, while that of the bromo-iodide is blackish brown. However, by suitable dilution of the developer both may be made darker and more intense. Of this more anon.

If a full exposure is given the image sometimes appears light brown and is bordered with dark brown. If the exposure is still further increased, solarization takes place. The exposed parts appear transparent, almost like clear glass, in the middle of an extensive halo; for this I burn 25^{cm} of magnesium ribbon, one to two centimeters in front of a plate, covered with a perforated screen. If the plate is prepared with silver iodide and bromide precipitated together, there is no solarization (I have used plates containing 5, 10 and 20 parts of AgI to 100 parts of AgBr). The exposed surface is then strongly blackened and stands out strongly from its wide transparent surroundings. This was also the case with prolonged exposures. All these experiments were made with plates containing gelatine. I have also tried silver bromide plates containing agar-agar, but found that they solarized even more readily than the gelatine plates. V. SCHUMANN.

Refraction in the Atmosphere of Jupiter.—M. Bélopolsky, in discussing the results of his spectrographic determination of the equatorial velocity of rotation of Jupiter (*A. N.* 3326), notes that the velocity determined in this way is less than that deduced from the observed rotation and micrometric measurements of the planet's diameter. Assuming a rotation period of $9^h\ 50^m$, different measures of the diameter give equatorial velocities varying from $12^{km}.1$ to $12^{km}.8$ per second, while the result of the spectrographic determination is $11^{km}.42$. M. Bélopolsky suggests that the measured diameter may be too great on account of refraction in the atmosphere of the planet, and points out that spectrographic determinations of the equatorial velocity of Saturn also give a result which is slightly too small.

At present the difference in question would seem to be too near the probable error of measurement to warrant a definite conclusion as to its reality, but the point is worth remembering as a subject for investigation with improved instruments in the future.

A large Telescope for Potsdam.—We learn with pleasure that the Astrophysical Observatory at Potsdam is to have a large refracting telescope. With the 11-inch refractor hitherto used for the spectrographic researches of Professors Vogel and Scheiner, the motions in the line of sight of 51 stars were determined with great accuracy, but it was impossible to photograph stars appreciably fainter than the second magnitude with the large spectrograph. It is reported from Berlin that the aperture of the new telescope will be about thirty inches. The light-collecting power of such an instrument should be sufficient to bring stars of the third magnitude and some even fainter ones within reach of the large spectrograph, whose range will thus be trebled if not quadrupled.

REVIEWS.

RECENT SPECTROSCOPIC WORK OF EDER AND VALENTA.

Über drei verschiedene Spectren des Argons. Sitzber. d. K. Akad. d. W. Wien. CIV. Dec. 1895. *Über die Spectren von Kupfer, Silber und Gold. Denksch. d. K. Akad. d. W. Wien.* LXIII. 1896.

Two interesting papers by Eder and Valenta of Vienna have just appeared giving accounts of two series of researches. One is a preliminary contribution on "The Three Different Spectra of Argon," and the other is a memoir on the "Spectra of Copper, Silver and Gold." In all of their preceding work Eder and Valenta have used a prism spectroscope; but, having secured a Rowland concave grating of short focus, they are now applying it to various investigations. Their instrument is set up in the usual manner; the slit is fixed, and the moving arm carries the grating and camera box. Great precautions and skill seem to have been used in the adjustments of the apparatus; and so the results obtained command confidence. All the wave-lengths are reduced to Rowland's scale, the method being to use some comparison spectrum on the same plate. An alloy of zinc, cadmium, and lead was generally used for this purpose.

In the paper on the spectra of argon, the writers call attention to the previous work of Kayser and of Crookes, and to the well-known fact that argon gives two spectra, the "blue" and the "red," depending mainly upon the pressure of the gas and the nature of the discharge through it. The paper being a preliminary one, only a few wave-lengths are given, mainly in the extreme ultra-violet. But the main interest lies in certain observations, which were made for the first time. When the pressure is low (2 to 10^{mm}) in the tube containing argon, the red spectrum is absent almost entirely; and the blue spectrum is prominent. But as the pressure is increased to 20^{mm}, the character of the spectrum is changed; and, if a very large induction coil with large condensers is used, a new spectrum is observed, which Eder and Valenta call the "white" spectrum. Some of the lines in the blue spectrum remain entirely unchanged; but others shift their positions by as much as ½ to 1 Ångström unit. This is claimed to be a genuine shift, not an apparent one owing to unsymmetrical shading. This is certainly a remarkable observation. If the pressure in the tube is extremely low ($\frac{1}{10}$ to 2^{mm}) the red spectrum may be made to entirely disappear by simply continuing the discharge through it for a long enough time. The writers also examined the glow at the positive and negative poles, and found the two spectra identical. Crookes, on the other hand, says that he has observed the red spectrum at the positive pole, and the blue at the negative.

In examining the spectra of copper, silver and gold, special precautions were taken to secure pure metals; and sparks were passed between these pure electrodes in an atmosphere of hydrogen. In each case there is a full account given of the work done by previous observers, and a comparison of results. The authors, though, have overlooked the paper by Crew and Tatnall in *Astronomy and Astrophysics*, November 1894, "On a New Method of Mapping the Spectra of Metals," which contains a list of wave-lengths of copper lines. The only previous investigations that are comparable at all with that of Eder and Valenta are Kayser and Runge's on the arc-spectra of these elements, Crew and Tatnall's on the arc-spectrum of copper, and Trowbridge and Sabine's on the spark-spectrum of copper. There is excellent agreement between the results of the two researches on the spark-spectrum, and also between those of the two on the arc-spectrum. But between the spark and the arc-spectra there are many differences. As Eder and Valenta pointed out in their work on the spark-and arc-spectra of zinc and cadmium, the character of the spectrum changes greatly when the discharge is changed from an arc to a spark; some lines disappear, many new ones appear, and the difference in wave-length between a spark-line and an arc-line may be very slight. So also in this work on copper, silver and gold. There are many discrepancies between the wave-lengths and intensities of lines observed by Eder and Valenta in the spark-spectrum, and those observed by Kayser and Runge in the arc-spectrum; but it seems extremely probable that these differences are genuine ones, not accidental. This might almost be expected. For in the arc the vapor is at a fairly constant temperature and pressure; whereas in the spark discharge temperature and pressure have no meaning. Each time a spark passes, portions of matter have their velocity tremendously increased; but the process is both sudden and irregular, so that it is doubtful if there is even an average condition of pressure or temperature which is constant. Consequently spark-spectra are necessarily more complicated and irregular in every way than arc-spectra.

This memoir on the spectra of copper, silver and gold is especially interesting and important because in the introduction to it Eder and Valenta give a detailed account of their methods of adjustment of the apparatus, and also a most satisfactory description of the different solutions and stains (or "light filters" as they call them), which they use to cut out overlapping spectra.

J. S. A.

Report of the Smithsonian Astrophysical Observatory for the year 1895. S. P. LANGLEY. Smithsonian Report for 1895. Pp. 74–80.

It was in 1891, or about five years ago, that the important work on the bolometric investigation of the infra-red solar spectrum, which was begun by Professor Langley at Allegheny nearly twenty years ago, was recommenced at the Smithsonian Astrophysical Observatory by a new method and with greatly improved apparatus. It is, therefore, somewhat surprising to find the present report, which is the fourth annual report issued from the Observatory, devoted almost entirely to a discussion of the instrumental conditions of working and of those elementary sources of error which are generally considered before such an important investigation is undertaken, or at least, before any of its results are published. The logic and practical advantages of this order of procedure are indisputable and are recognized by every scientific man. It is, therefore, only fair to Professor Hallock and to myself to point out that all of the sources of error which the report deals with, as well as others of almost equal importance which are not there considered, were not only fully recognized, but carefully investigated three years ago, while we were (successively) the senior assistants in the Observatory. The present report contains nothing upon this point that could not have been stated, and in fact was stated in substance in the reports for 1892 and 1893. In this connection it will be well to indicate a misstatement in regard to one of the important sources of error, *i. e.*, that which is spoken of as due to a change in *potential* of the batteries. The true source of difficulty is not the change of potential in itself, but the *resulting change* in the strength of current in the bridge circuit as a whole. A change of potential of the batteries is of course only *one* of the causes which may produce this latter effect. To avoid it, it is necessary to keep the current constant to within about one-millionth of an ampere, and this the writer was accustomed to do by the use of a delicate Thomson galvanometer connected in shunt to the bridge circuit. Another of the errors spoken of, viz., that due to a change of temperature of one of the bridge coils, is of such a fundamental character and so generally recognized in accurate resistance measurements, as to hardly have needed mention. In regard to the errors arising from magnetic and seismic disturbances, it would seem that their importance had been somewhat exaggerated. We can never get rid of all disturbances of this nature, no matter where we may locate our laboratories, and it would seem better to overcome the difficulties due to them by means which are now well known and are comparatively simple of application, than to go to the expense and inconvenience of relocating an already fairly well established observatory. Vibration may practically be completely absorbed by mounting the instruments on a series of heavy slabs of stone separated from each other by blocks of soft rubber (as described in my article on the Galvanometer in the *Phil. Mag.* for Dec., 1894), or by floating them in mercury (Michelson's method), and magnetic disturbances guarded against by a soft iron enclosing case. The work of Professor Rowland and his associates and students at Johns Hopkins in the measurement of wave-lengths, both in the visible and the infra-red spectrum, and the work of Professor Boys at Oxford in the determination of the Newtonian Constant (reviewed in the last number of this JOURNAL), show what may be accomplished in the way of exact measurement under natural conditions (of vibration, etc.) far more unfavorable than those which exist (or did exist in 1892–3) at the Smithsonian Observatory. We do not wish to be understood as in any way depreciating the great advantages which result from the most favorable location of our laboratories and observatories; we only wish to question whether undue emphasis is not perhaps laid on this condition, especially in the statement made at the close of the report that, "It should finally be repeated as the most important conclusion of the year, that the final degree of precision attainable can never be reached in the present site."

One thing which deserves commendation in this report, is the acknowledgment of the fact that the so-called "linear translation" or "cylindric" of the region between wave-lengths 14000 and 22000, which was shown at the British Association meeting for 1894, and reproduced and commented upon at some length in the Observatory report for the same year, cannot be regarded as a trustworthy representation of the region in question. It is unfortunate that this representation was ever presented at all; still more unfortunate that such prominence should have been given to it as it received. In the paper read before the British Association, at which time the representation in question was first shown, Mr. Langley says, "Now considering that the part of the infra-red solar spectrum under review, extends through nearly two degrees. . . . . we may see for ourselves that at any rate over 2000 lines if they exist can be mapped. But these lines do exist, the whole of this new region being apparently as intimately filled with them as the visible spectrum by the Fraunhofer lines. In further evidence of this I now show a portion of the lower spectrum in the comparatively unknown part extending from $\lambda = 1^{\mu}.4$ to $\lambda = 2^{\mu}.2$, including the great band Ω shown as a single inflection in my first communication to this Association, but here resolved into thirty or more subordinate lines . . . . in the small portion here exhibited it may be seen that about 200 lines are discriminated." Again in the Observatory report for 1894 he further adds, "The result of the work has been extremely satisfactory so far as regards the number and importance of the lines found. The accompanying illustration showing a portion of the infra-red spectrum from the region $1^{\mu}.4$ to $2^{\mu}.2$, beyond what a few years ago was considered the limit of the infra-red spectrum, will show the detail and clearness with which the present apparatus is capable of rendering what can, only in the absence of a better word, be called the 'appearance' of this region. . . . The portion of the infra-red spectrum shown, which is that at present furthest advanced, has been gone over several times, and each of the more than 200 lines which occupy this plate has been verified by many observations. The plate shows but a small part of the region which is now being mapped, in all of which it is believed the results will be equally encouraging." [1]

This plate was also reproduced in the second number of this JOURNAL in illustration of a review of the work by Professor Hale and has been frequently copied in other journals. But as far as I have been able to find, Professor Hale is the only one who has questioned the truth or accuracy of the representation, and his criticisms were directed only against the method of translation or reproduction from the original energy curve. Now whatever may be the degree of confidence placed in the original energy curves and in the method of obtaining these "cylindrics" from them, there is a very simple criterion which has been entirely overlooked and which declares at once absolutely against the truth of the final result. *Many of the lines shown are closer together than the spectroscope used* (a single rock-salt prism of about 9^{cm} aperture) *could theoretically resolve.* Since the width of the slit with which the energy curves were taken, was never less than $0^{mm}.3$, the *purity* of the spectrum in this region ($\lambda = 20000$) was only about one-half the theoretical resolving power, and the absolute impossibility of recording all of the lines shown even under *perfect* conditions of observation is at once evident. This shows again how important it is, especially in spectroscopic work, to understand clearly the optical capabilities and limitations of our instruments before drawing conclusions from either visual, photographic or bolometric observations. As Professor Keeler has very aptly said in a recent review, "Expressions of individual opinion have no weight in matters which are governed by purely physical laws." But there is also another special lesson to be drawn from this case, and that is the superiority of the energy curve itself to any "linear translation" or "cylindric" as a representation of bolometric results. No such erroneous conclusions could have been drawn from the energy curves of this region had they been presented in the same way that those showing the whole of the infra-red region were presented, for it would have been evident at once that the minute deflections which were translated into lines in the cylindric were accidental and not real. No question can be raised as to the accuracy and truthfulness of the main features of the three superposed curves which were shown in the report for 1894, and in this JOURNAL in the article already referred to. The results expressed by these curves were certainly sufficiently important and represented sufficient advance in themselves to have made it unnecessary to accompany them with maps in regard to the truth of which there could have been any question.

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[1] I have not been able to find either in the British Association paper or in the Observatory reports, the statement which Professor Langley quotes that this plate of the spectrum "was presented only in illustration" and was "not to be treated as a criterion of the final results." Without this the statements quoted above would certainly leave the impression that the results spoken of were regarded as trustworthy.

It is a satisfaction to note that in spite of the recent retrenchment of national expenses and the consequent reduction in the appropriations for nearly all of the governmental departments, there has been no reduction in that for the prosecution of this work for the present year. The government appropriations for this work alone have already amounted to nearly $50,000: as large as if not a larger sum than has ever before been available for any one scientific investigation, but no larger perhaps than is commensurate with its interest and importance. It is to be hoped that this generous support will be continued in the future as it has been in the past.

F. L. O. WADSWORTH.

RECENT PUBLICATIONS.

A LIST of the titles of recent publications on astrophysical and allied subjects will be printed in each number of THE ASTROPHYSICAL JOURNAL. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors.

For convenience of reference, the titles are classified in thirteen sections.

1. THE SUN.

BOMPAS, G. C. The Sun's Path in Space. Obs'y, **19**, 126, 1896.

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NOTICE.

The scope of THE ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

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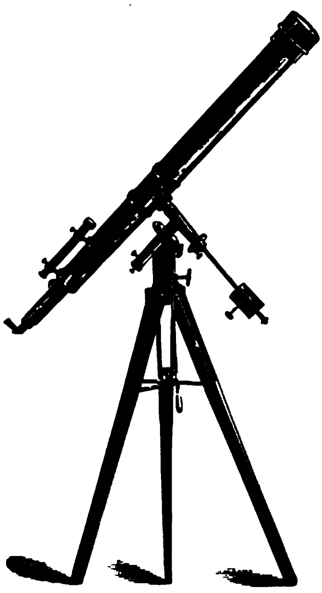

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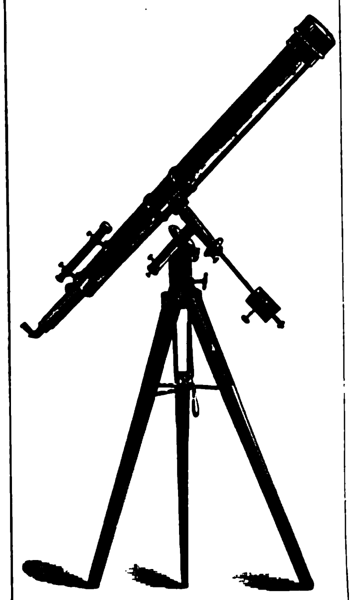

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>
> —GILBERT, "De Magnete."

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NOTICE

TERRESTRIAL MAGNETISM will appear four times a year, viz., during the months of January, pril, July, and October. A volume will consist of four numbers, embrace about 200 pages and begin ith the January issue.

Communications relating to the subject matter of the Journal, as broadly defined and suggested the title, are solicited. All languages that can be printed with Roman characters will be admitted. *e of the main languages, however, should be used whenever possible.* The manuscript must be legibly itten, type-written when possible, *in Roman script* and on one side of the paper only. If drawings ch as are absolutely essential) accompany the article they should be drawn in India ink and neatly ished.

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Announcement.

With the January, 1896, issue appears the first number of a Journal devoted exclusively to Terrestrial Magnetism, and its allied subjects such as Earth Currents, Auroras, Atmospheric Electricity, etc. No apology will be made for thus adding one more to the already over large list of scientific periodicals. Indeed, it is this very multiplicity, making it possible for articles on Terrestrial Magnetism to appear anywhere but specially nowhere, that has made the need of concentration keenly apparent to the lovers of the science.

Primarily, the aim of this Journal will be, to create a broader sympathy and to afford an easier communication between widely separated workers in a field that is day by day receiving greater recognition and whose possibilities have not yet been fathomed ; secondarily, to increase the army of workers and of students.

Without doubt one of the chief wants of Terrestrial Magnetism to-day is a convenient channel for the timely and friendly interchange of ideas among the specialists in the science. *There is not a single journal, at present, that supplies this want.* The literature is in consequence scattered over many and miscellaneous periodicals, often well-nigh buried away in obscure publications or in such as are only accessible to a select few. In how far the Journal will fulfill its prime purpose will depend principally upon the co-workers in the science. Now that Terrestrial Magnetism has an organ of its own—and that an international one—it behooves them to do their utmost to make the Journal in every sense a success and thus to justify the important step Terrestrial Magnetism has taken.

It is also the firm belief that the Journal should make it a special object to *increase* the ranks of the devotees by enlisting the interests of all the men of science who can contribute, whether directly or indirectly, towards the advance of the subject, such as astronomers, geographers, geologists, meteorologists, particularly, however, physicists and mathematicians. Here is a field full of interesting and fascinating problems, both of an experimental and of a theoretical nature, which can form the basis of legitimate and fruitful investigations. It is the intention, therefore, to have recognized authorities review the progress made in the various phases of the subject and to point out the direction in which further research is desirable and essential.

The day has gone by for studying the phenomena of the magnetized needle chiefly by reason of their possible value to the mariner and the surveyor. The higher view, ushered in by Humboldt and Hansteen, but most fully recognized by Gauss, that Terrestrial Magnetism is a subject worthy of the profoundest physical and mathematical study, has taken firm root and is steadily, though slowly, making progress. It gave birth to the famous Magnetic Union headed by Gauss and Weber. The epoch-making results which were the direct and indirect outcome of this magnetic association were equally beneficial to Terrestrial Magnetism and to science in general. It taught the physicist, among other things, how to make absolute magnetic measurements, and soon revealed to the scientific world that the earth's magnetism is in sympathetic touch not alone with terrestrial but also with *cosmical* influences. Hence, gravitation is not the only bond that binds us in friendly union with our sister planets and our parent sun. The magnetic needle thus has become a most promising instrument of research, not alone in terrestrial but also in cosmical physics. *No other mechanical means is so surely and so completely recording the physical history of terrestrial and cosmical changes as the self-registering magnetographs of our magnetic observatories, whereby the fitful tremors of the delicately suspended magnetic needle are being indelibly fixed on the sensitized sheet. "On that paper, as Maxwell eloquently expressed it, the never resting heart of the earth is now tracing in telegraphic symbols, which will one day be interpreted, a record of its pulsations and its flutterings, as well as of that slow but mighty working [the secular variation] which warns us that we must not suppose that the inner history of our planet is ended."* This extract suffices to give a hint as to the possibilities of geomagnetic investigations. In directing our eyes and energies skyward to unravel the phenomena of the starry firmament, let us not forget that the Earth, too, has its secrets and its mysteries that ought to be disclosed. Is it not *geophysical* observatories, *generously* equipped and endowed, that we especially need today?

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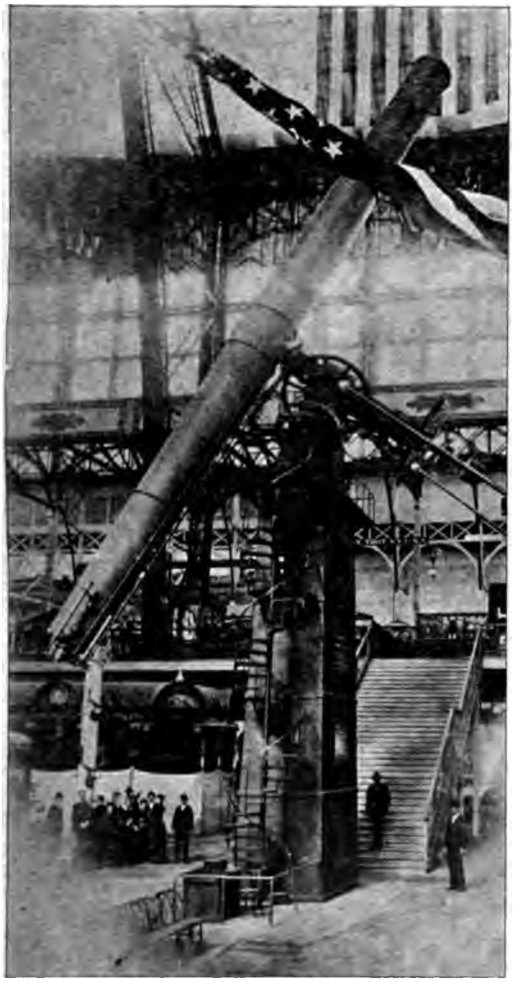

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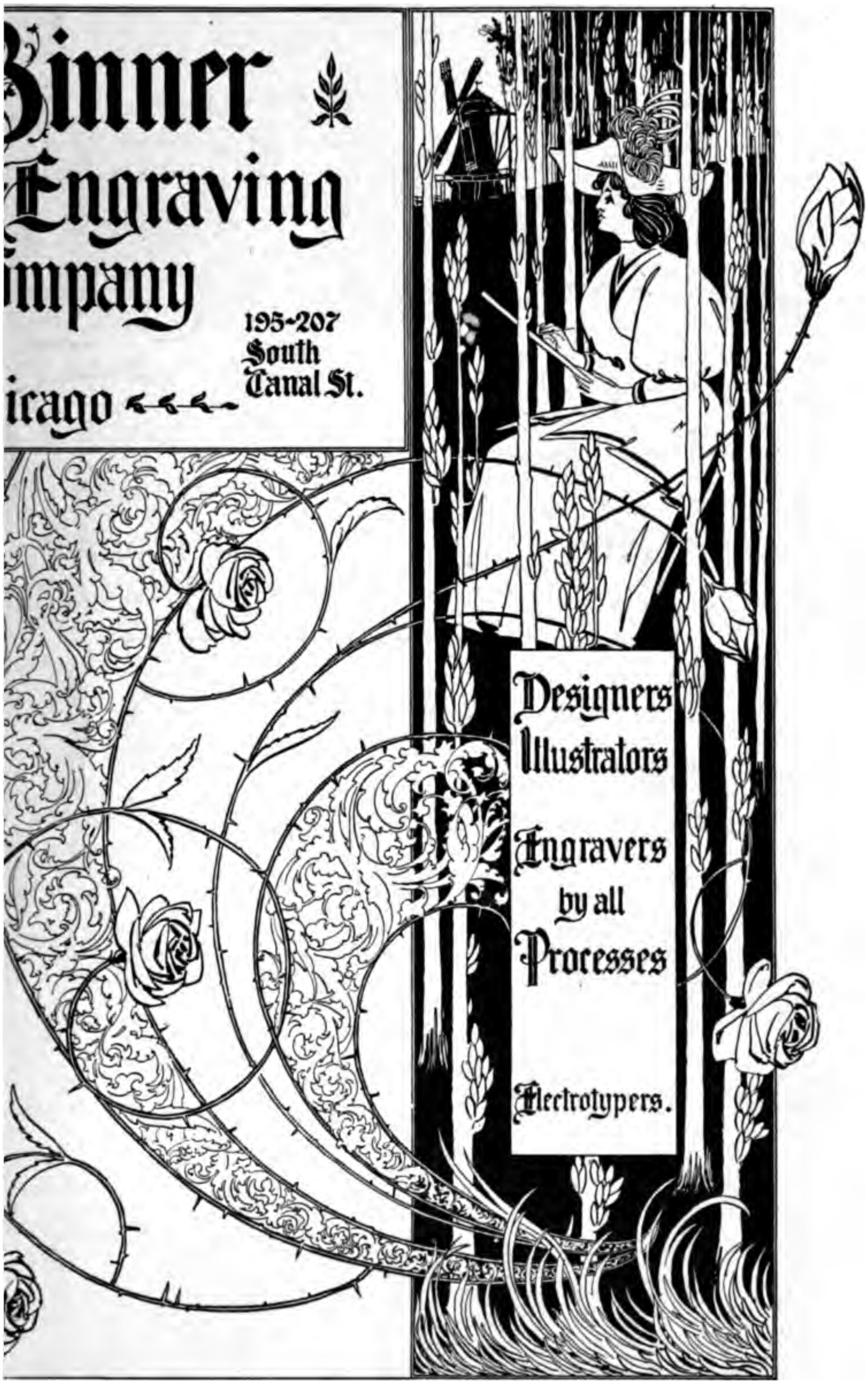

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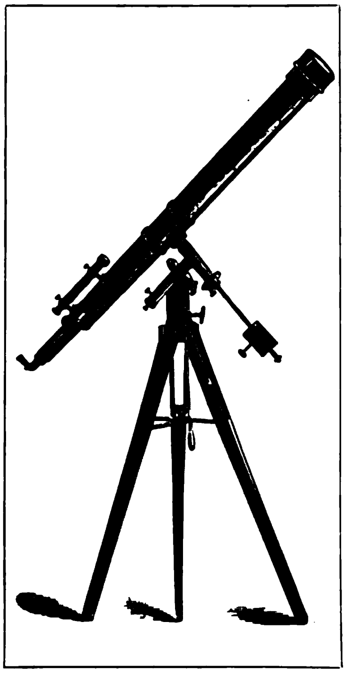

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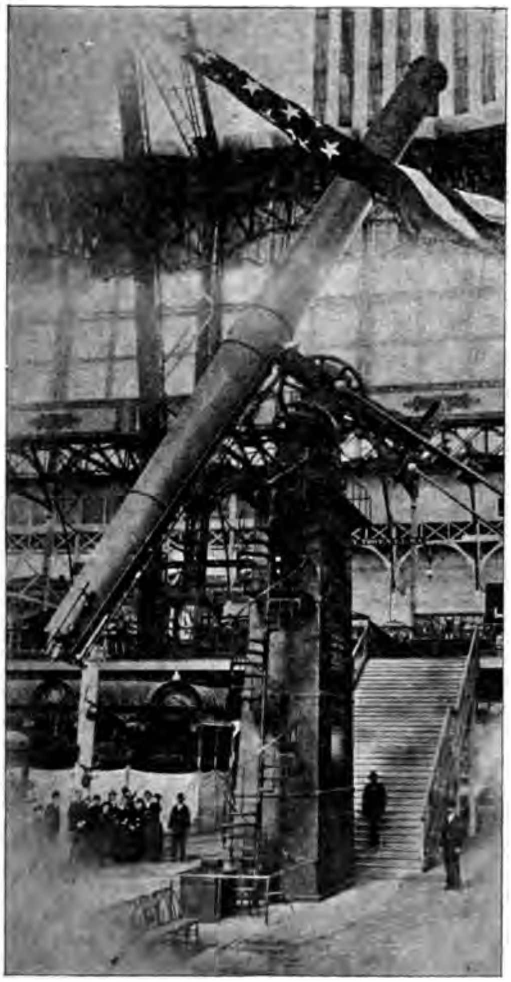

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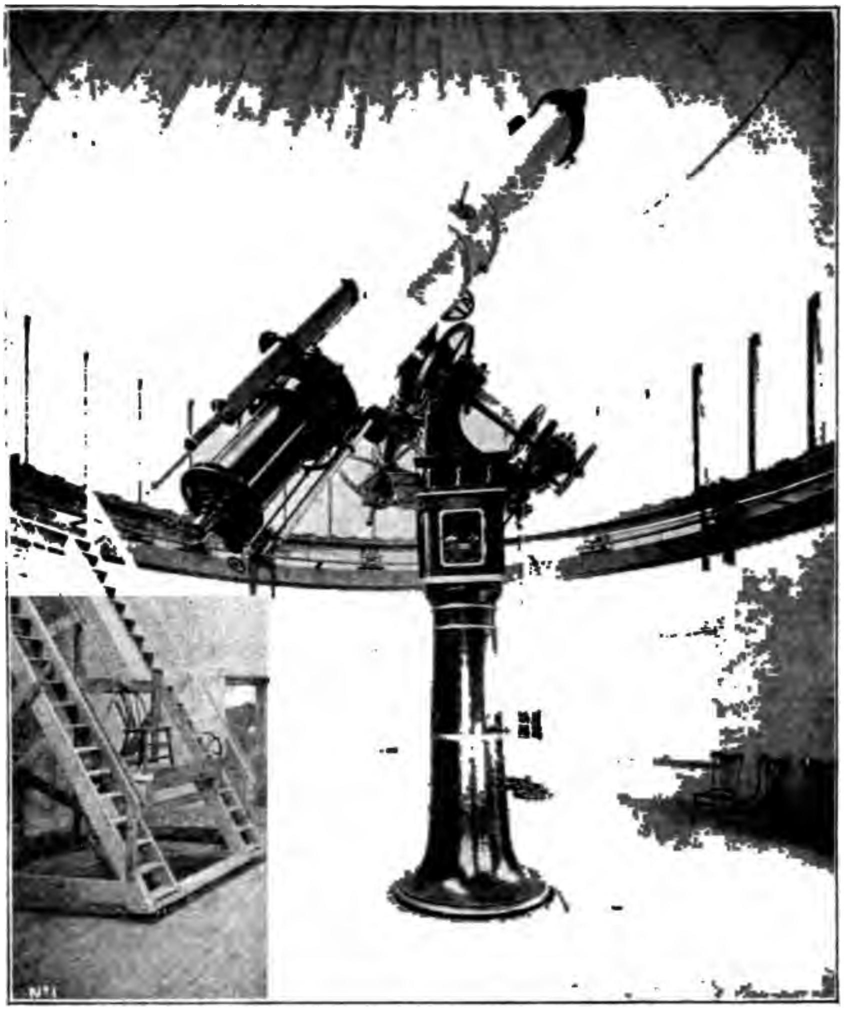

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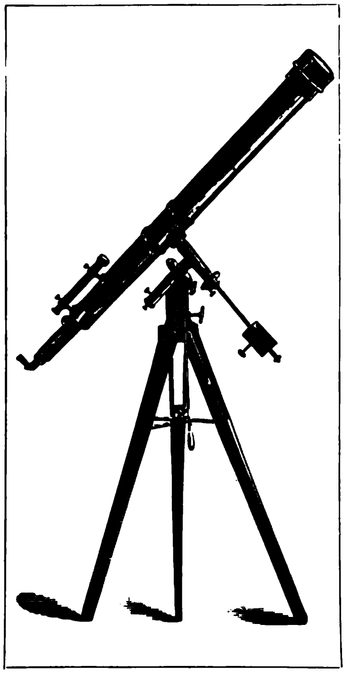

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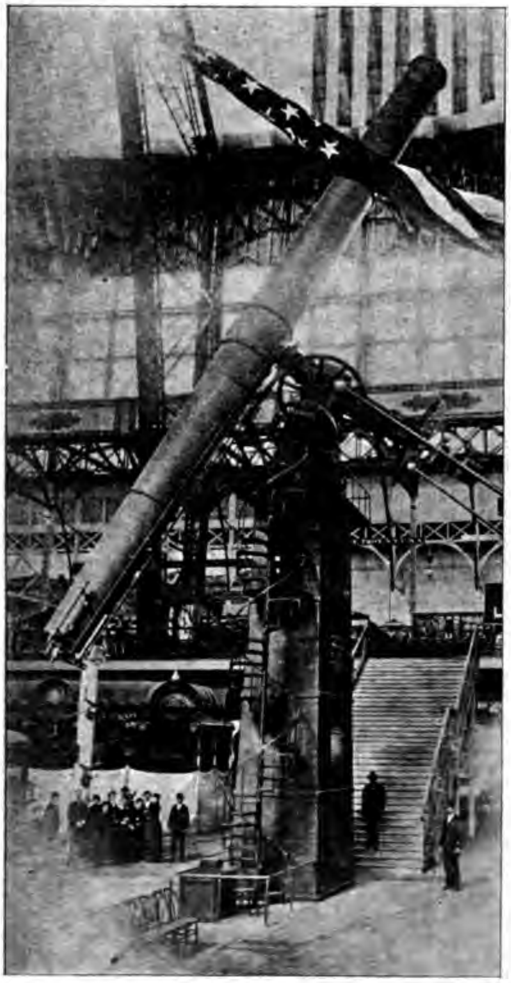

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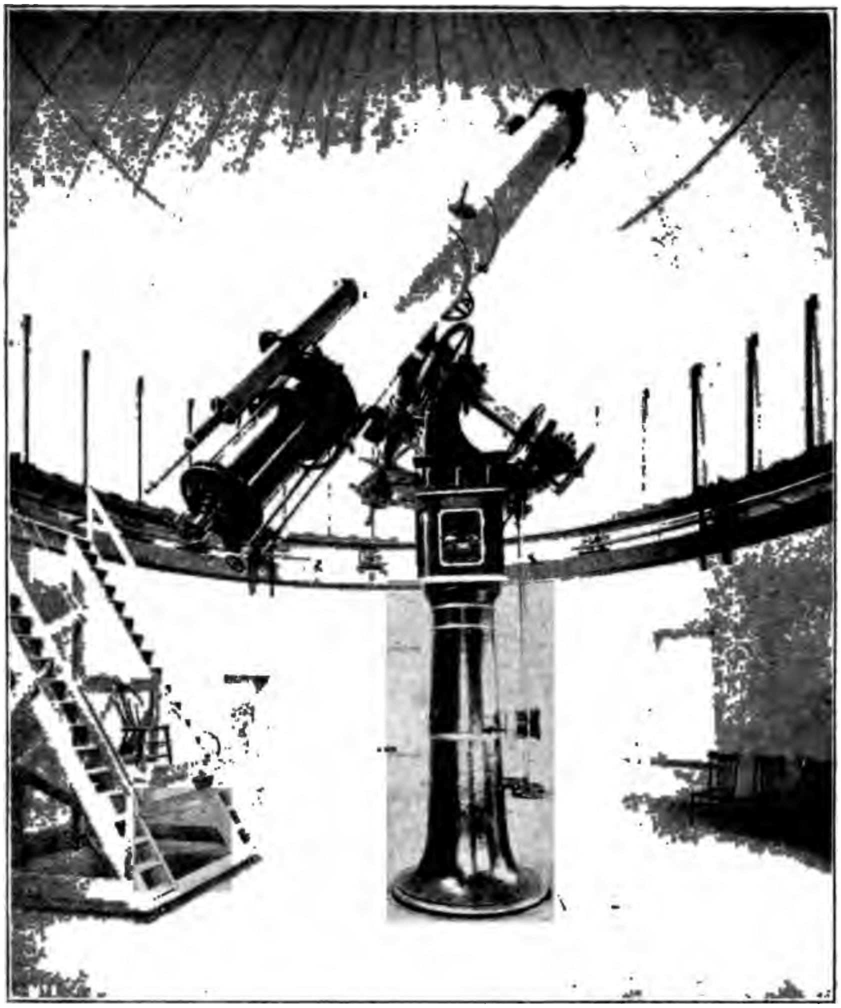

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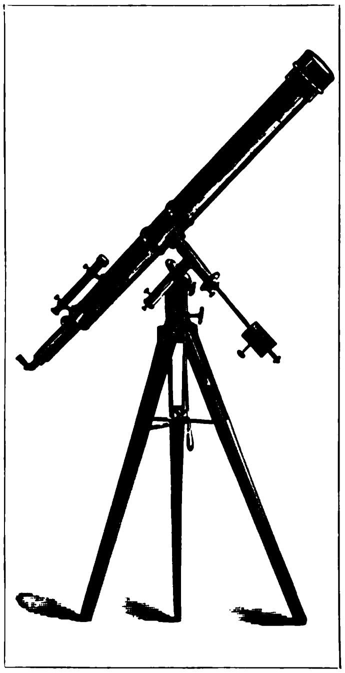

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